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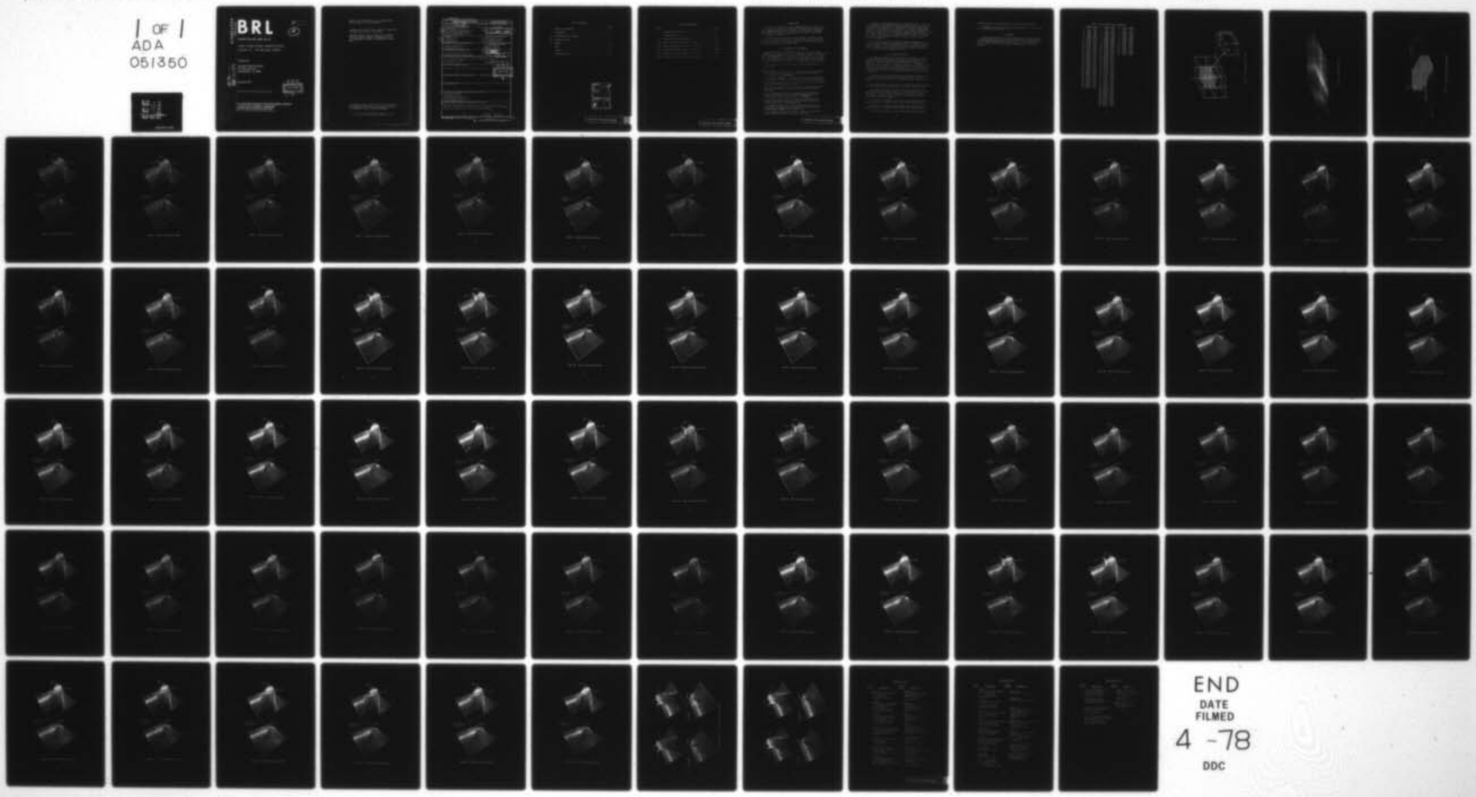

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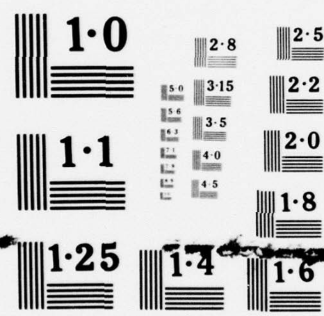
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CONTRACT REPORT ARBRL-CR-355

THREE-DIMENSIONAL COMPUTATIONS, VOLUME III: 60° OBLIQUE IMPACT

Prepared by

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December 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Numerical calculations were made in 1975 of four oblique impact problems; 30°, 45°, 60°, and 77.5°. A graphical display of the results of the 60° deg impact of a copper jet on a steel target are presented.

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I. INTRODUCTION

A series of four oblique impact computations (30°, 45°, 60°, and 77.5°) involving a copper jet impacting a steel plate were completed in 1975 for the Ballistic Research Laboratory.[1] This work was performed using TRIDORF[2] and DORF[3,4] and ancillary programs CUBIT[3] and ADJUST[4] under Contract No. DAAD05-75-C-0738.

The effort for 1976 has been directed towards a graphical display of the data from these computations. The four oblique impacts in the series are presented in sequential volumes[5,6,7] with the results of the 60° obliquity impact being reported here.

II. DESCRIPTION OF THE PROBLEM

The 60° oblique impact computation involved a copper jet with a 0.7086-mm radius impacting on a 12.7-mm thick steel target. The obliquity angle is measured between the normal to the target and the axis of the jet. Since TRIDORF uses a retangular grid, the copper jet was treated as a bar with a square cross section of 1.256-mm width, thus preserving the cross-sectional area of the jet. The impact velocity was 7.55 km/s.

The Tillotson[8] form of the equation of state was used for the computations.

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1. W. E. Johnson, "Three-Dimensional Computations on Penetrator-Target Interactions," Ballistic Research Laboratory Contractor Report No. 338, May 1977. (AD #A041058)

2. W. E. Johnson, "TRIDORF - A Two-Material Version of the TRIOIL Code with Strength," Computer Code Consultants, CCC-976, September 1976.

3. W. E. Johnson, "Code Correlation Study," Air Force Weapons Laboratory Report No. AFWL-TR-70-144, April 1971.

4. W. E. Johnson, "Development and Application of Computer Programs to Hypervelocity Impact," Systems, Science and Software, 3SR-749, July 1971.

5. W. E. Johnson and V. Kucher, "Three-Dimensional Computations, Volume I: 30° Oblique Impact", Ballistic Research Laboratory Contractor Report No. 344, July 1977. (AD #A043295)

6. W. E. Johnson and V. Kucher, "Three-Dimensional Computations, Volume II: 45° Oblique Impact", Ballistic Research Laboratory Contractor Report No. 354, November 1977.

7. W. E. Johnson and V. Kucher, "Three-Dimensional Computations, Volume IV: 77.5° Oblique Impact", Ballistic Research Laboratory Contract Report ARBRL-CR-356, December 1977.

8. J. H. Tillotson, "Metallic Equations of State for Hypervelocity Impact," Gulf General Atomic, GA-3216, July 1962.

A view of a three-dimensional grid is shown in Figure 1. Each cell is identified by the coordinates (I,J,K), which number the cells in the x,y,z-directions, respectively. The overall size of the computational grid was x = 33.139 mm by y = 55.270 mm by z = 9.732 mm. The maximum number of cells in the x-direction was I = 40, in the y-direction, J = 52, and in the z-direction, K = 17. The total number of cells in the grid was 35,360. Table I presents the dimensions of the cells, DX, DY, and DZ, and the grid coordinates as shown in Figure 1. These data are displayed in Figure 2.

The xy-plane was used as a plane of symmetry through the bar in order to keep the number of computational cells at a minimum. Since the width of the bar was four cells, the bar was two cells wide from the plane of symmetry. Figure 3 shows the penetrator-target configuration as it is located in the computational grid.

III. GRAPHICAL RESULTS

The numerical output of the computations is presented as density and pressure fields. The density and pressure are plotted on a two-dimensional spatial plane having the coordinates corresponding to the centers of cells. The fields are plotted such that a cell-number coordinate is held constant. For example, K may be constant meaning that the density or pressure is being presented for the cells between two z-planes bounding the K-cells. These bounding planes will be indicated in each figure. Figures 2 and 3 should be useful for orienting oneself in the grid.

The density scale for the density field plots can be realized from the initial density of the jet and the target, 8.9 and 7.8 Mg/m^3, respectively. The density scale is the same in all the density field plots.

The pressure scale is not the same in all the pressure field plots; therefore, the maximum pressure, Pmax, is indicated on each figure.

The first set of figures, Figures 4-20, shows the density and pressure fields at a constant time of 2.04 μs for various K-slabs which are numbered from the plane of symmetry. The jet appears distinct only when K = 1 and K = 2 since, initially, the jet was two cells in width from the plane of symmetry.

The second set of figures, Figures 21-37, shows the density and pressure fields at a constant time of 2.74 μs for various K-slabs.

The third set of figures, Figures 38-54, shows the density and pressure fields at a constant time of 3.09 μs for various K-slabs.

The fourth set of figures, Figures 55-65, shows the density and pressure fields at a constant time of 3.46 μs for various K-slabs.

A comparison of the density and pressure fields at $K = 1$ for various times is shown in Figures 66-67.

IV. SUMMARY

Numerical computations were made in 1975 of oblique impact problems. A graphical display of the results of the 60° impact of a copper jet on a steel target are presented for future analysis. The results for the 30°, 45°, 60°, and 77.5° oblique impacts are presented in sequential volumes.

Table I. Grid Coordinates and Cell Dimensions

I	x (mm)	DX (mm)	J	y (mm)	DY (mm)	K	z (mm)	DZ (mm)
1	2.847	2.847	1	3.495	3.495	1	0.314	0.314
2	4.541	1.694	2	6.990	3.495	2	0.628	0.314
3	5.896	1.355	3	8.790	1.800	3	0.942	0.314
4	6.980	1.084	4	10.390	1.600	4	1.256	0.314
5	7.965	0.985	5	11.790	1.400	5	1.601	0.345
6	8.861	0.896	6	12.990	1.200	6	1.981	0.380
7	9.675	0.814	7	13.990	1.000	7	2.399	0.418
8	10.415	0.740	8	14.790	0.800	8	2.859	0.460
9	11.088	0.673	9	15.390	0.600	9	3.365	0.506
10	11.707	0.619	10	15.890	0.500	10	3.921	0.556
11	12.263	0.556	11	16.290	0.400	11	4.540	0.619
12	12.769	0.506	12	16.604	0.314	12	5.213	0.673
13	13.229	0.460	13	16.918	0.314	13	5.953	0.740
14	13.647	0.418	14	17.232	0.314	14	6.767	0.814
15	14.027	0.380	15	17.546	0.314	15	7.663	0.896
16	14.372	0.345	16	17.860	0.314	16	8.648	0.985
17	14.686	0.314	17	18.174	0.314	17	9.732	1.084
18	15.000	0.314	18	18.488	0.314			
19	15.314	0.314	19	18.802	0.314			
20	15.628	0.314	20	19.116	0.314			
21	15.942	0.314	21	19.430	0.314			
22	16.256	0.314	22	19.744	0.314			
23	16.570	0.314	23	20.058	0.314			
24	16.884	0.314	24	20.372	0.314			
25	17.229	0.345	25	20.686	0.314			
26	17.609	0.380	26	21.000	0.314			
27	18.027	0.418	27	21.314	0.314			
28	18.487	0.460	28	21.628	0.314			
29	18.993	0.506	29	21.973	0.345			
30	19.549	0.556	30	22.353	0.380			
31	20.168	0.619	31	22.771	0.418			
32	20.841	0.673	32	23.231	0.460			
33	21.581	0.740	33	23.737	0.506			
34	22.395	0.814	34	24.293	0.556			
35	23.291	0.896	35	24.912	0.619			
36	24.276	0.985	36	25.585	0.673			
37	25.360	1.084	37	26.325	0.740			
38	26.715	1.355	38	27.139	0.814			
39	28.409	1.694	39	28.035	0.896			
40	33.139	4.730	40	29.020	0.985			
			41	30.104	1.084			
			42	31.459	1.355			
			43	33.153	1.694			
			44	35.270	2.117			
			45	37.770	2.500			
			46	40.270	2.500			
			47	42.770	2.500			
			48	45.270	2.500			
			49	47.770	2.500			
			50	50.270	2.500			
			51	52.770	2.500			
			52	55.270	2.500			

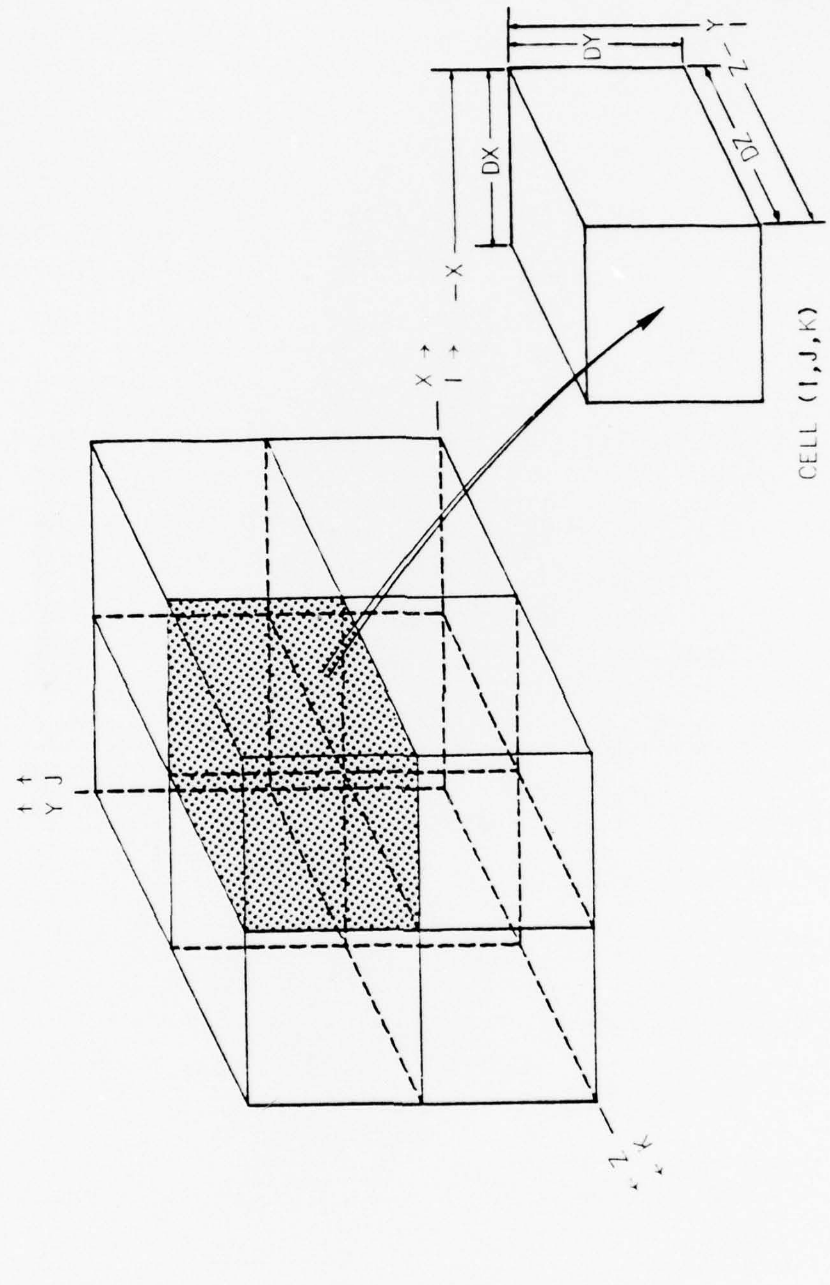


Figure 1. A Three-Dimensional Grid

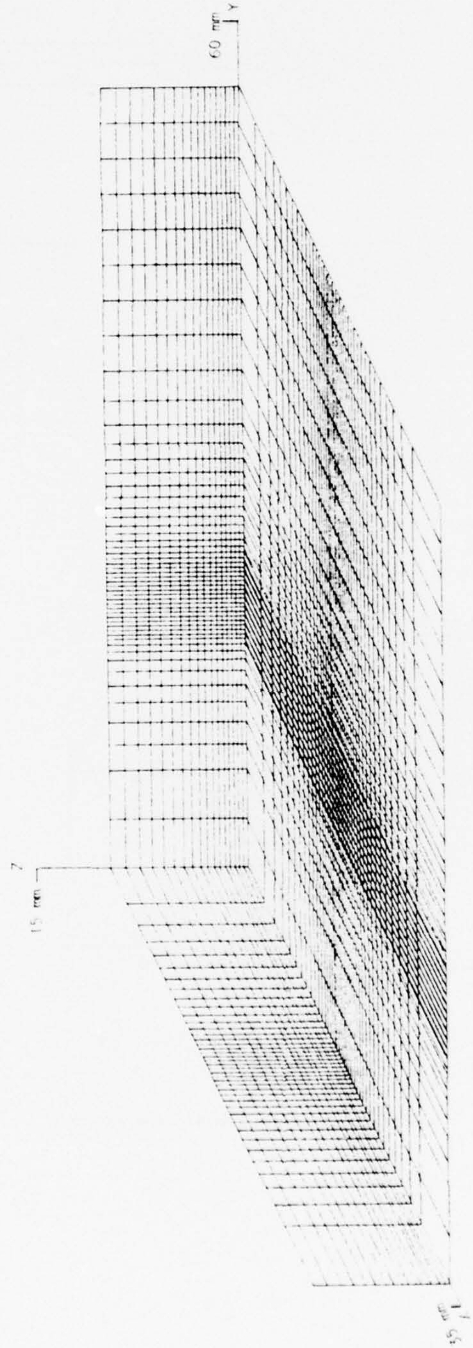


Figure 2. Computational Grid

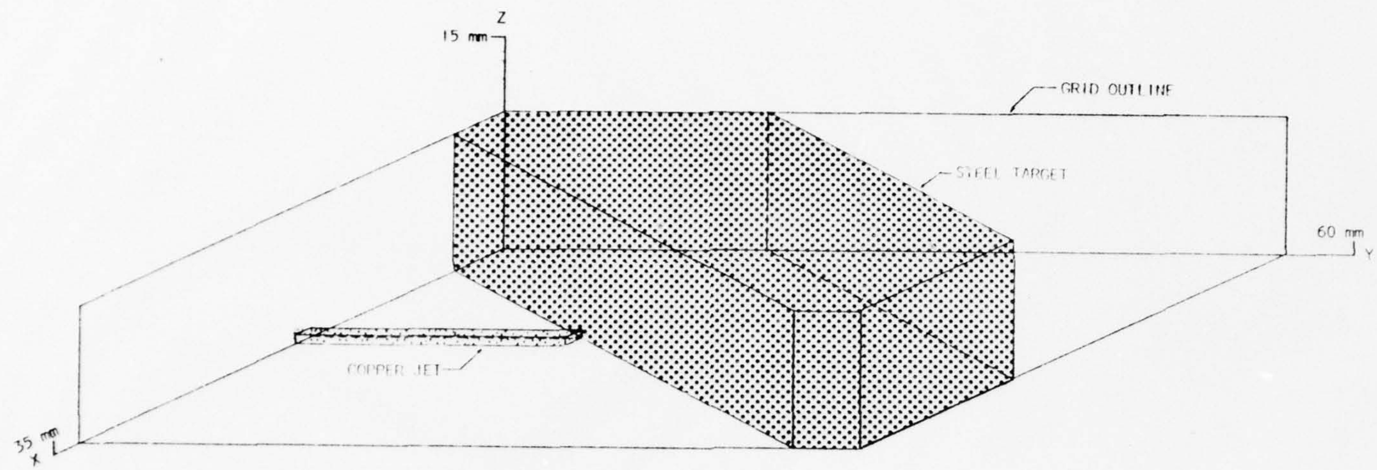
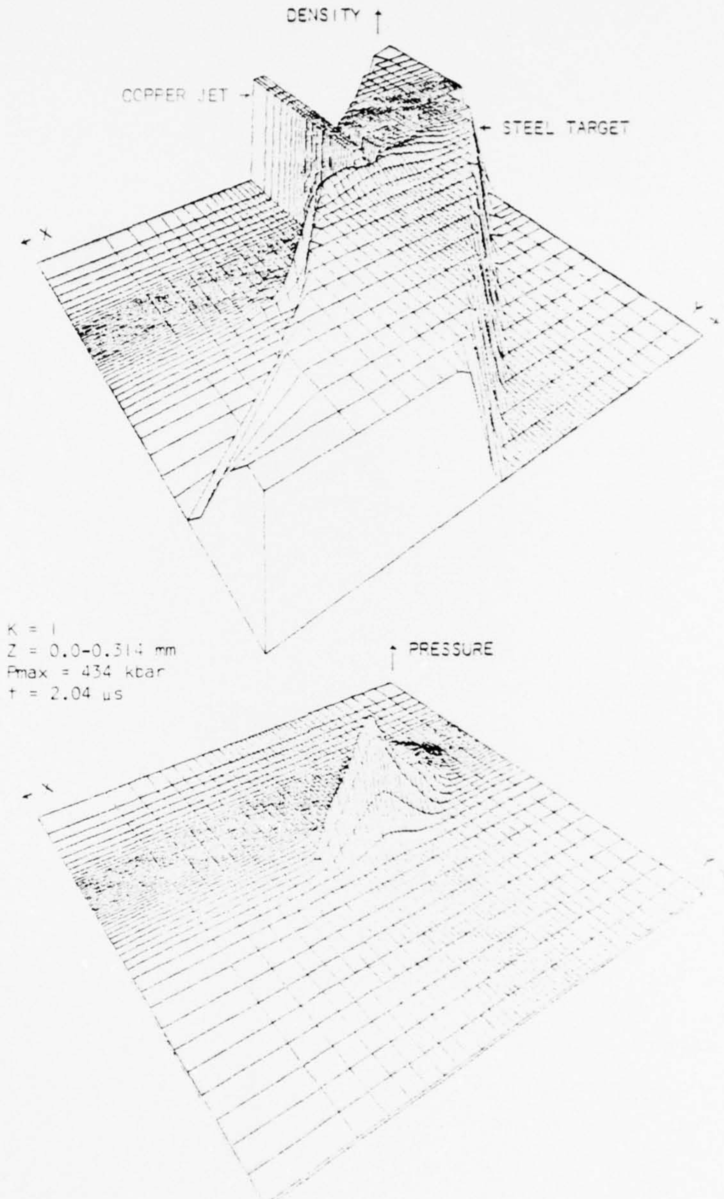


Figure 3. Penetrator-Target Configuration



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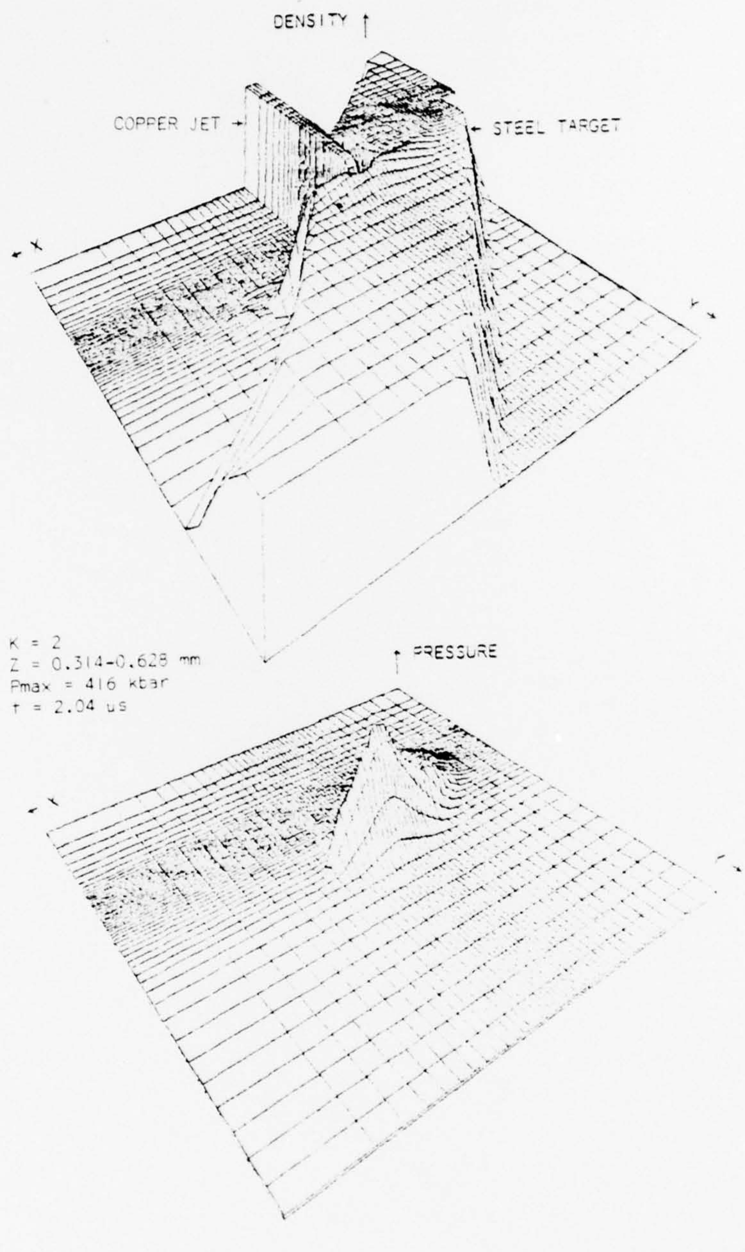

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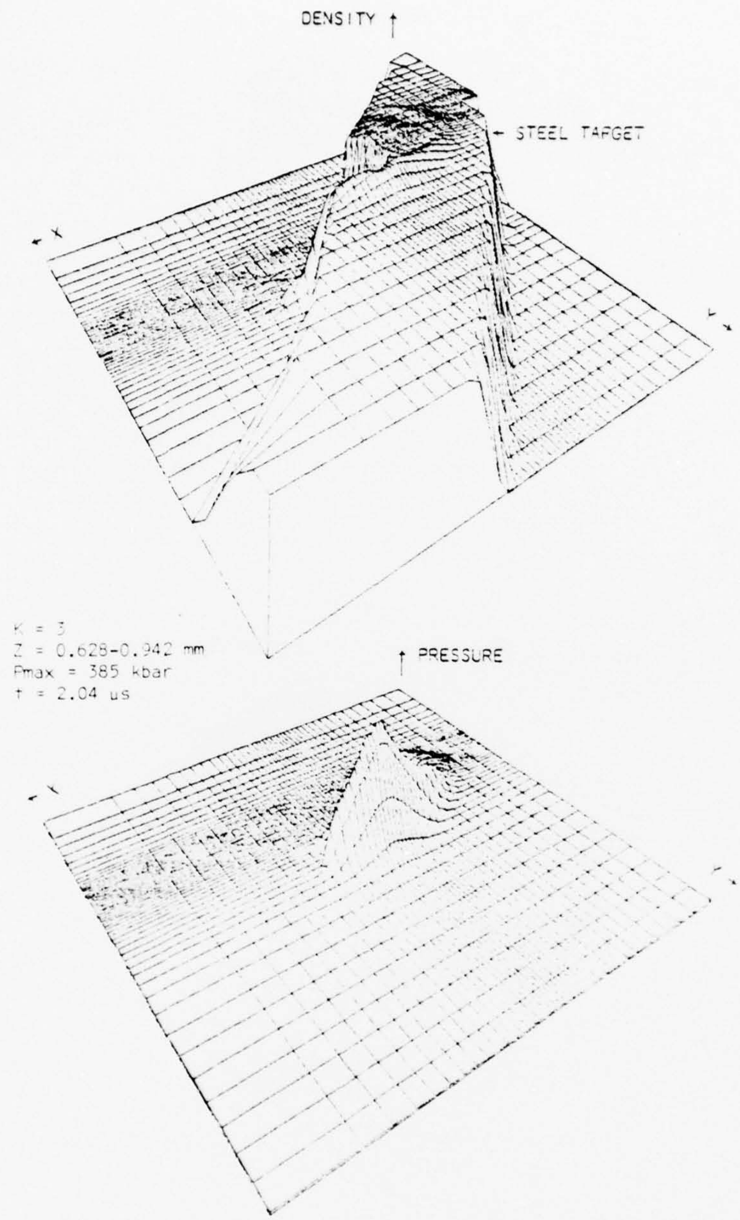

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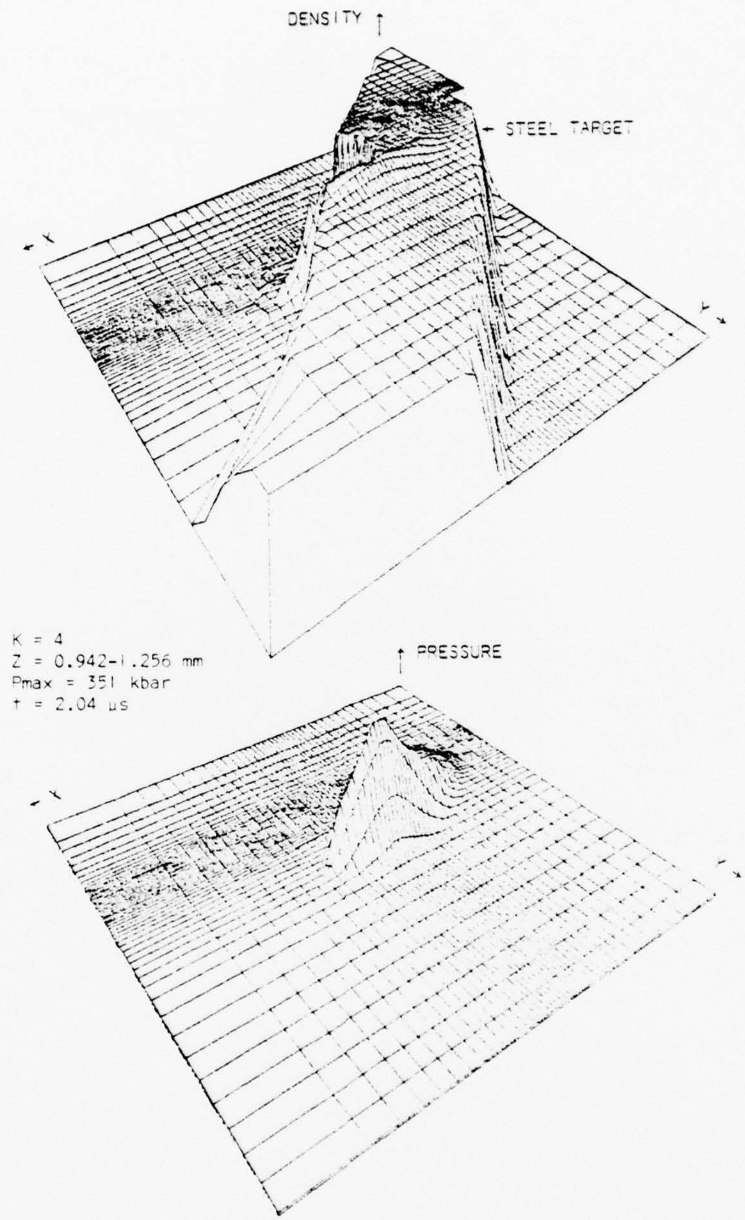

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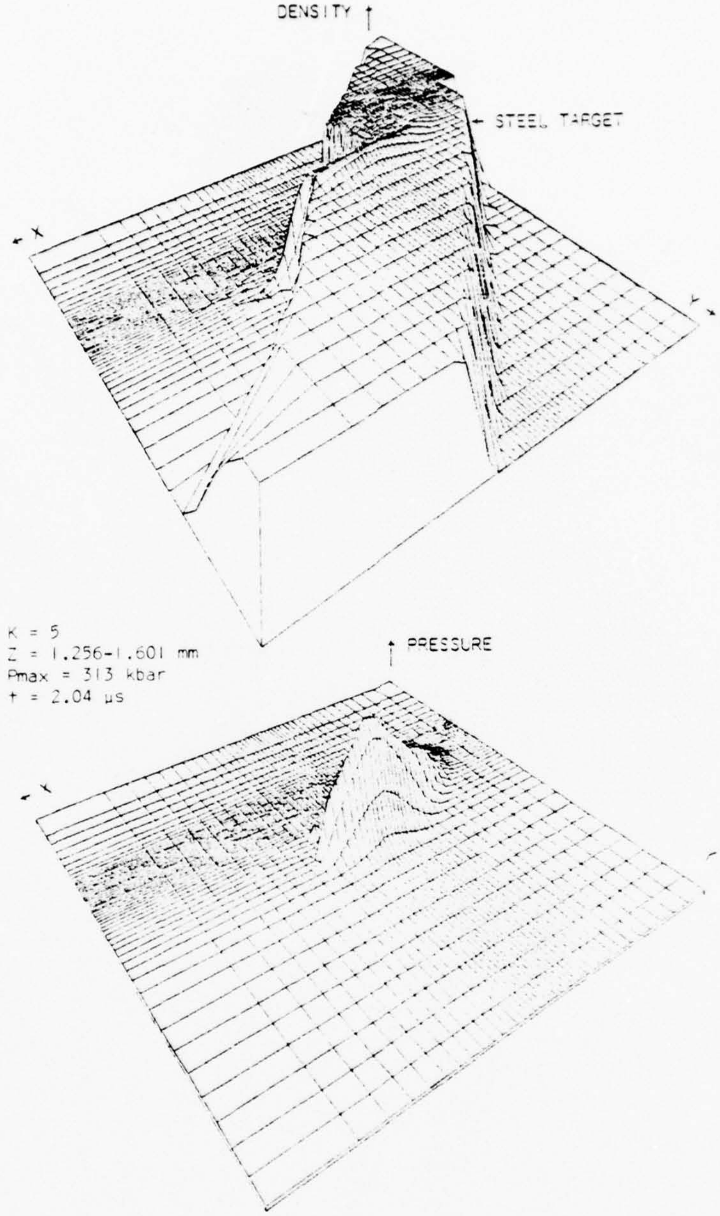

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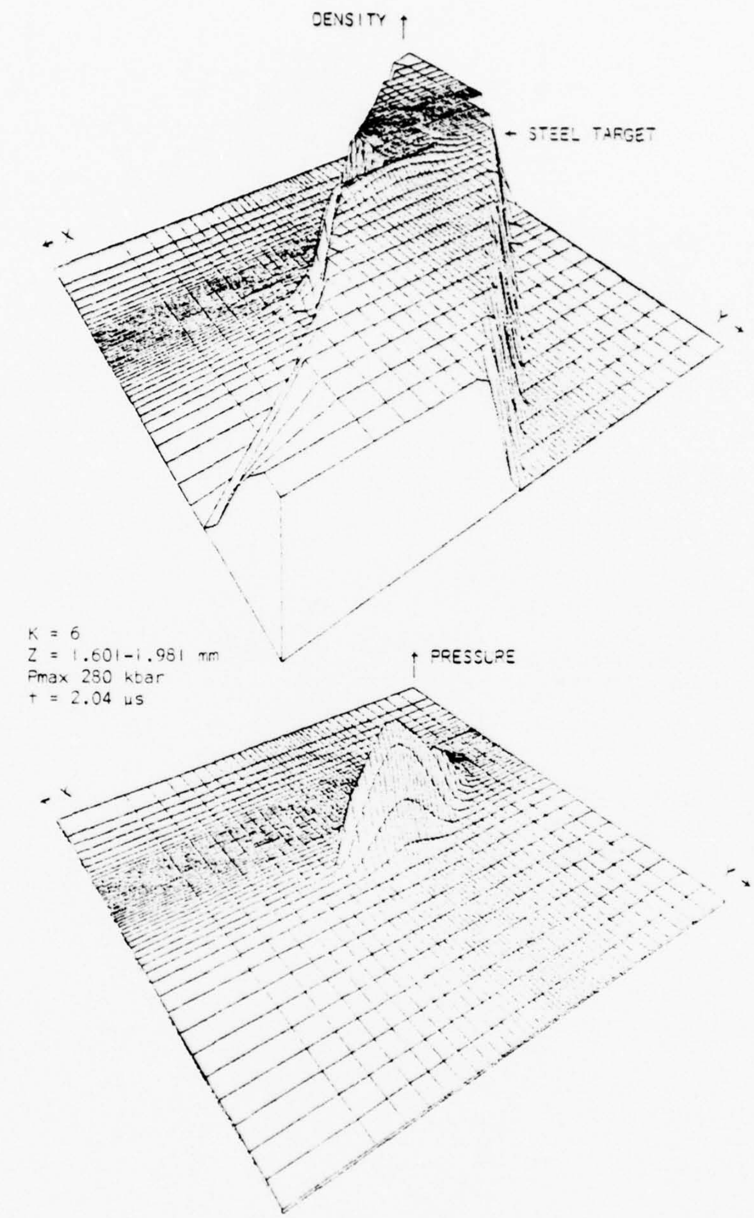

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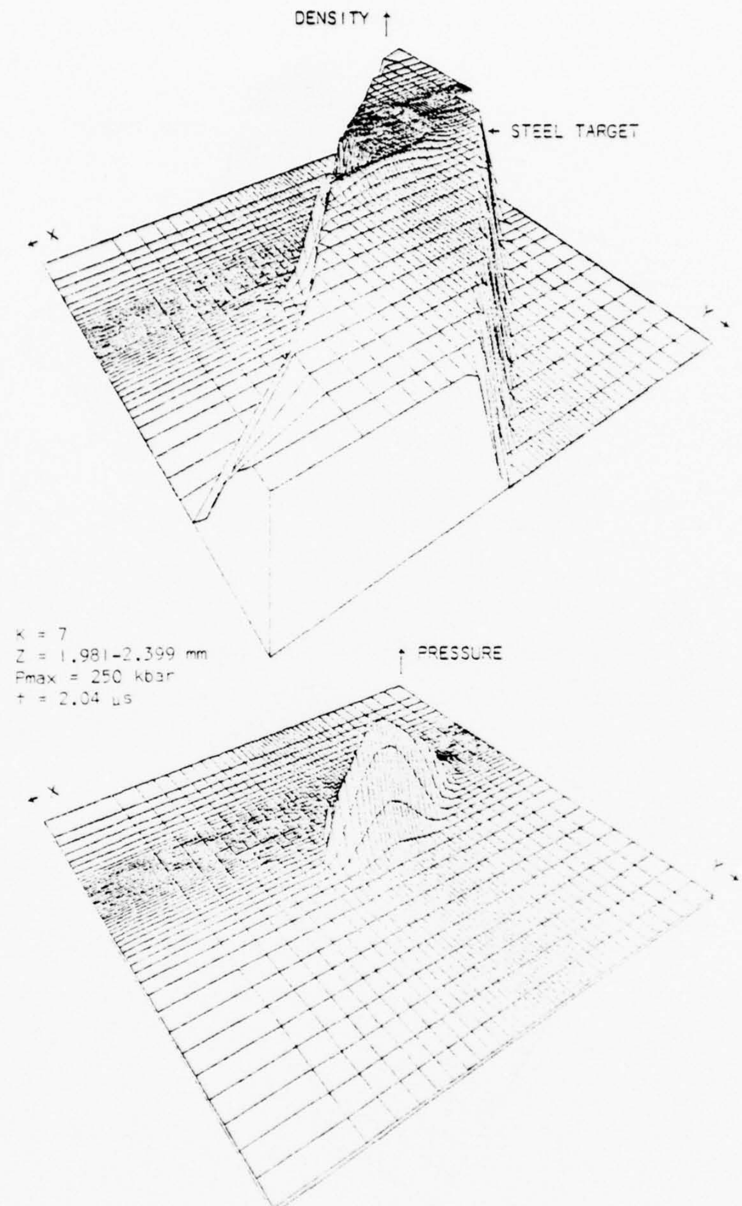

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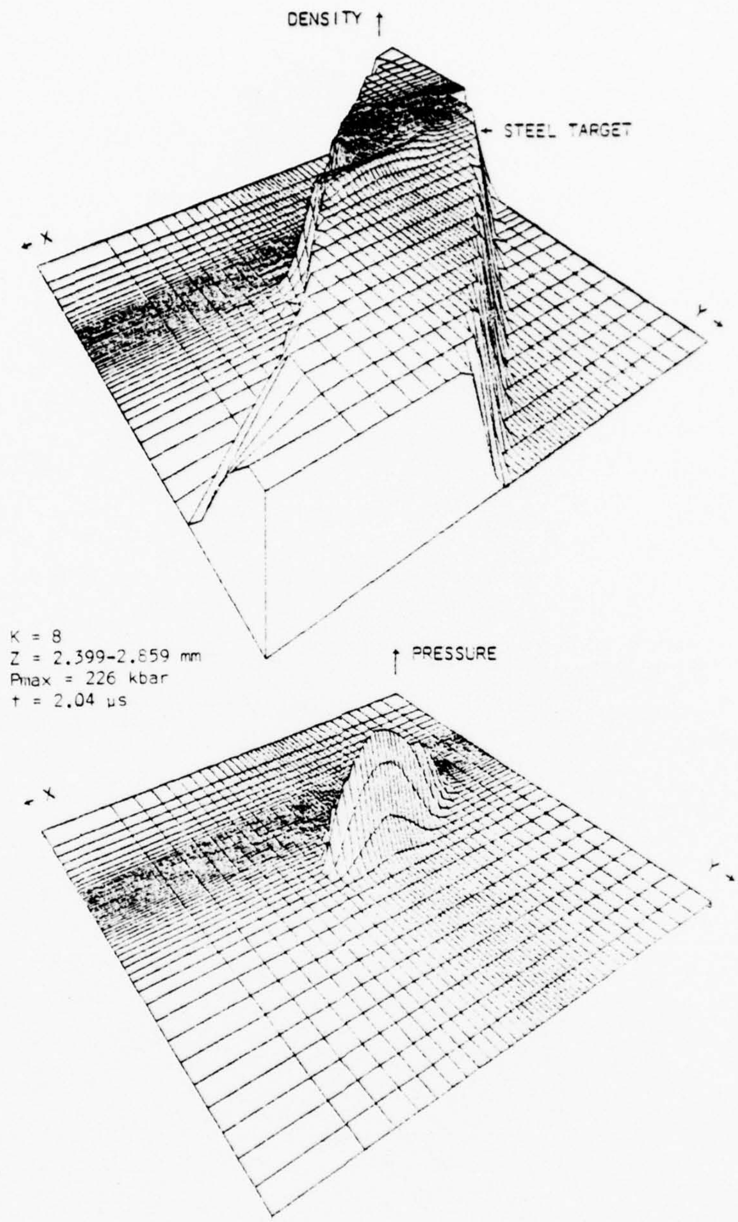

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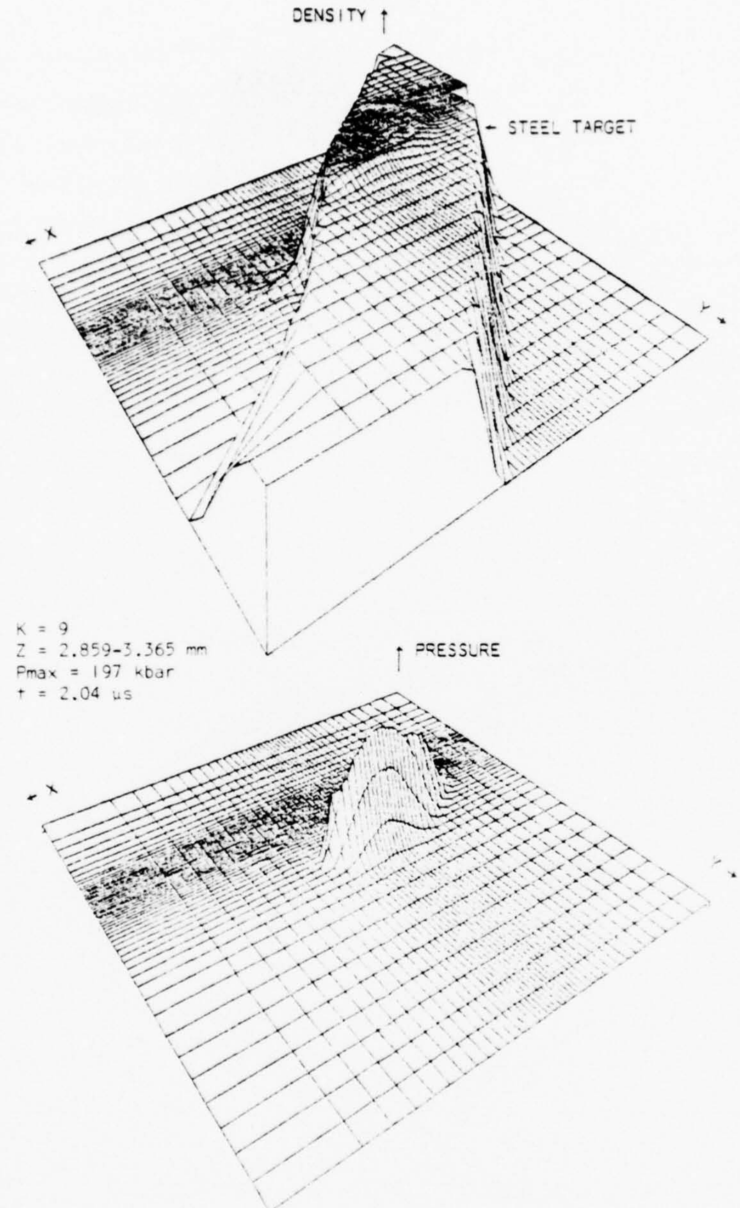

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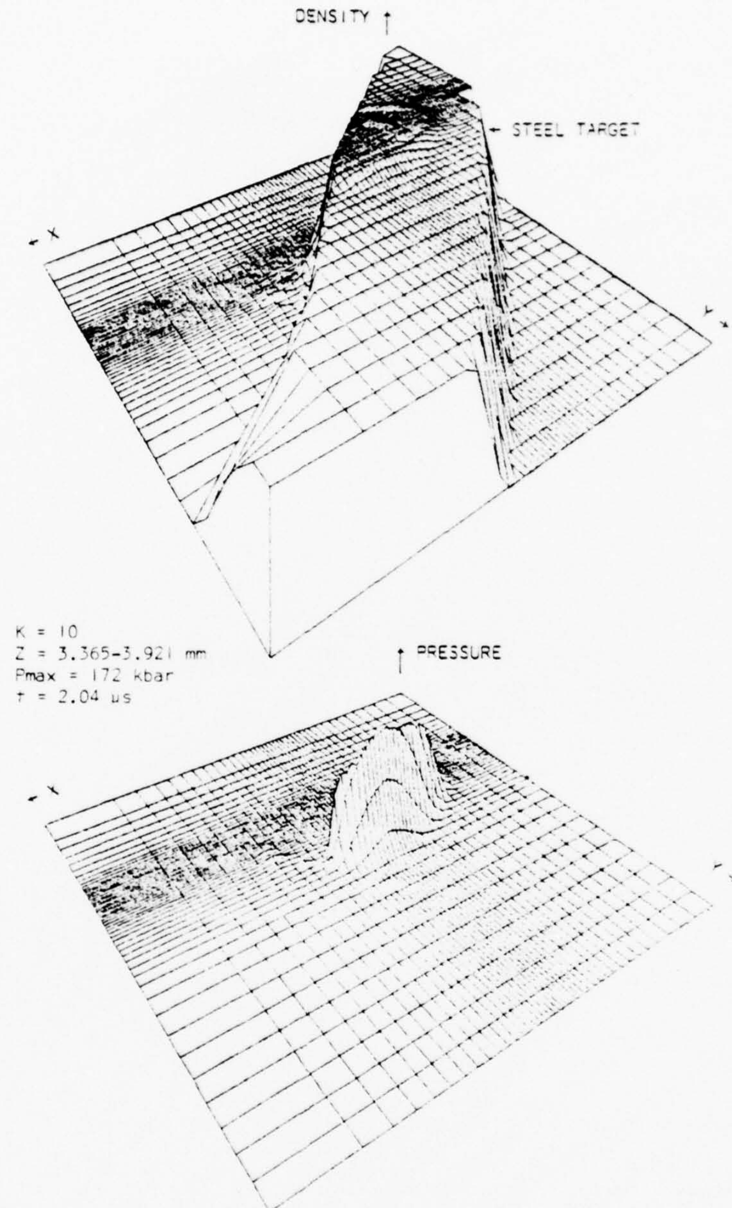

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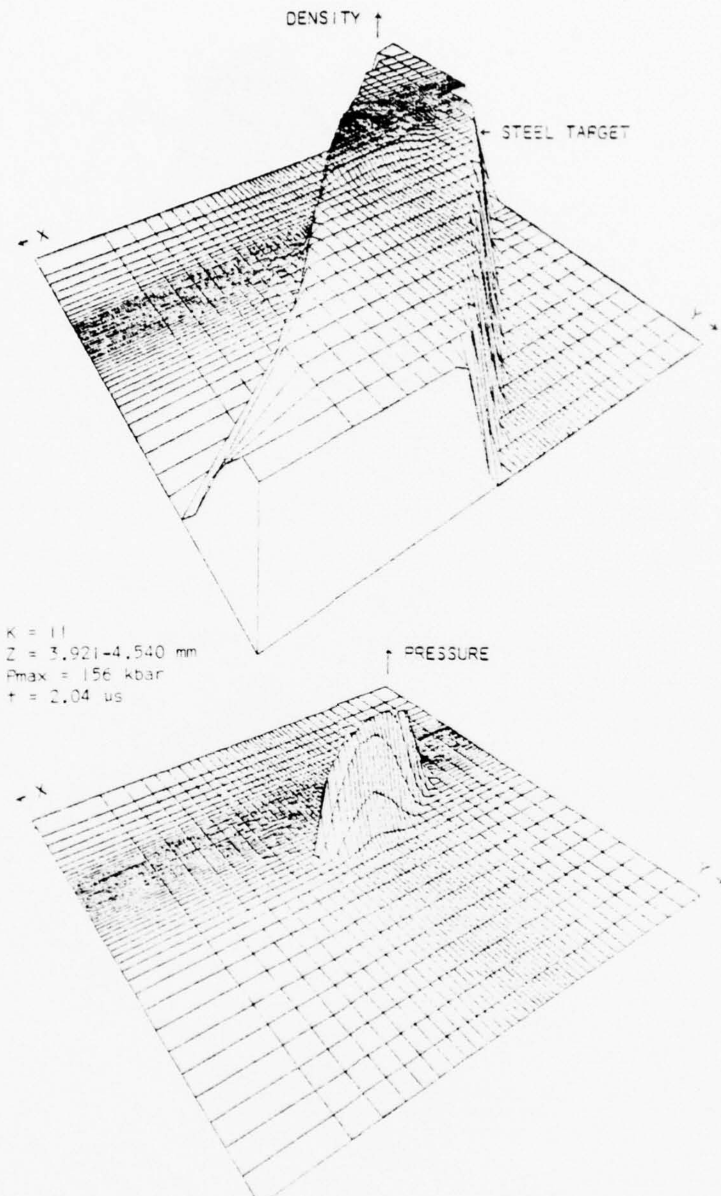

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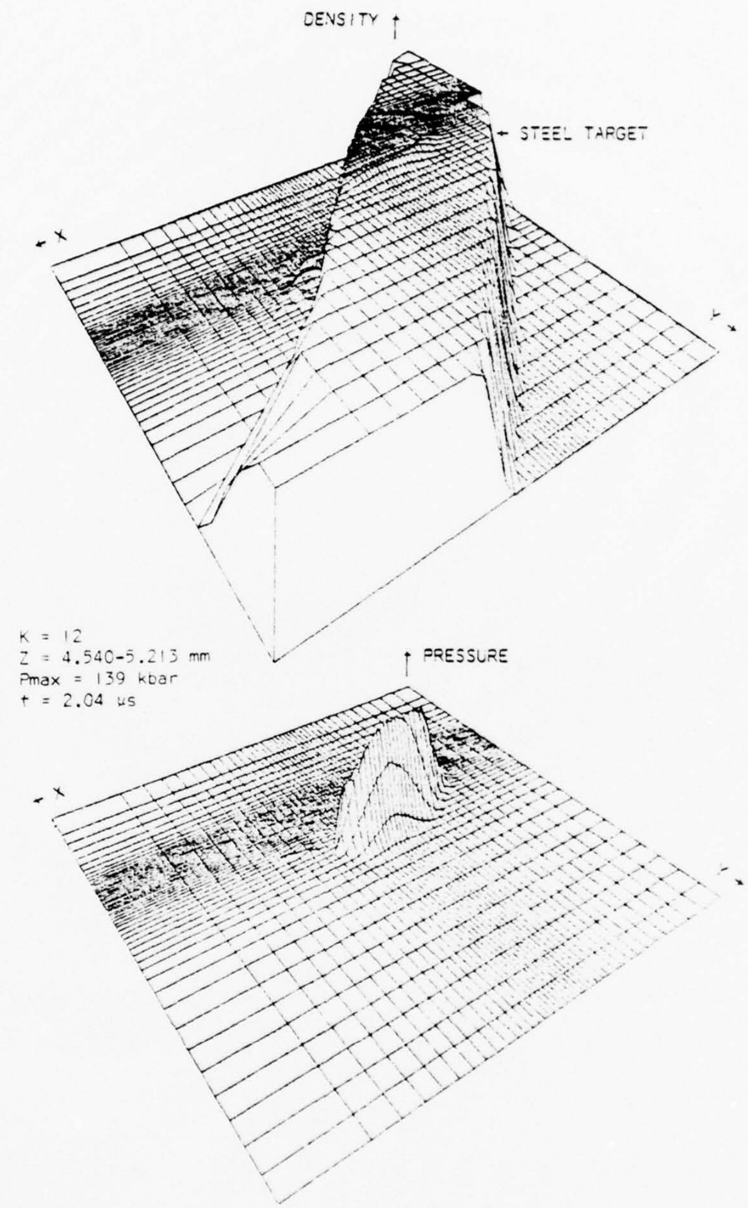

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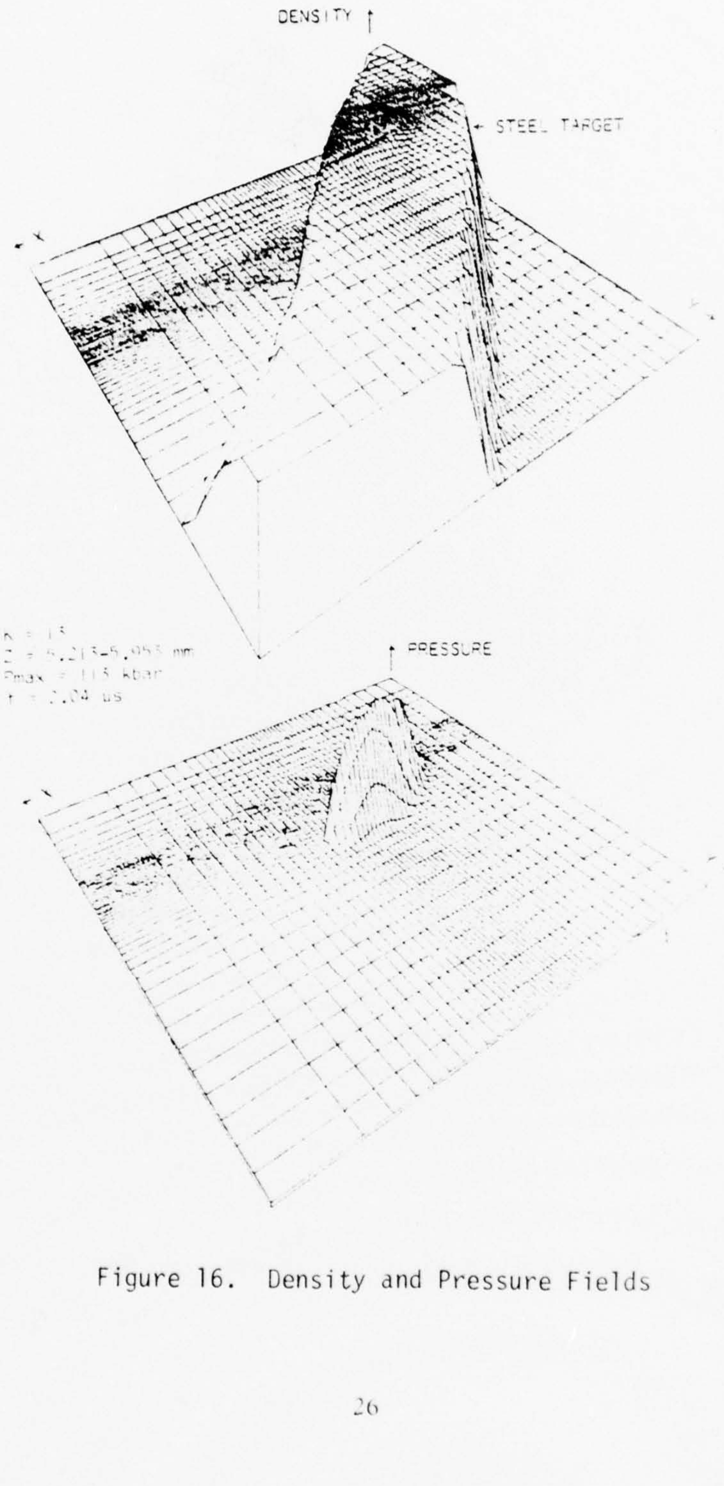

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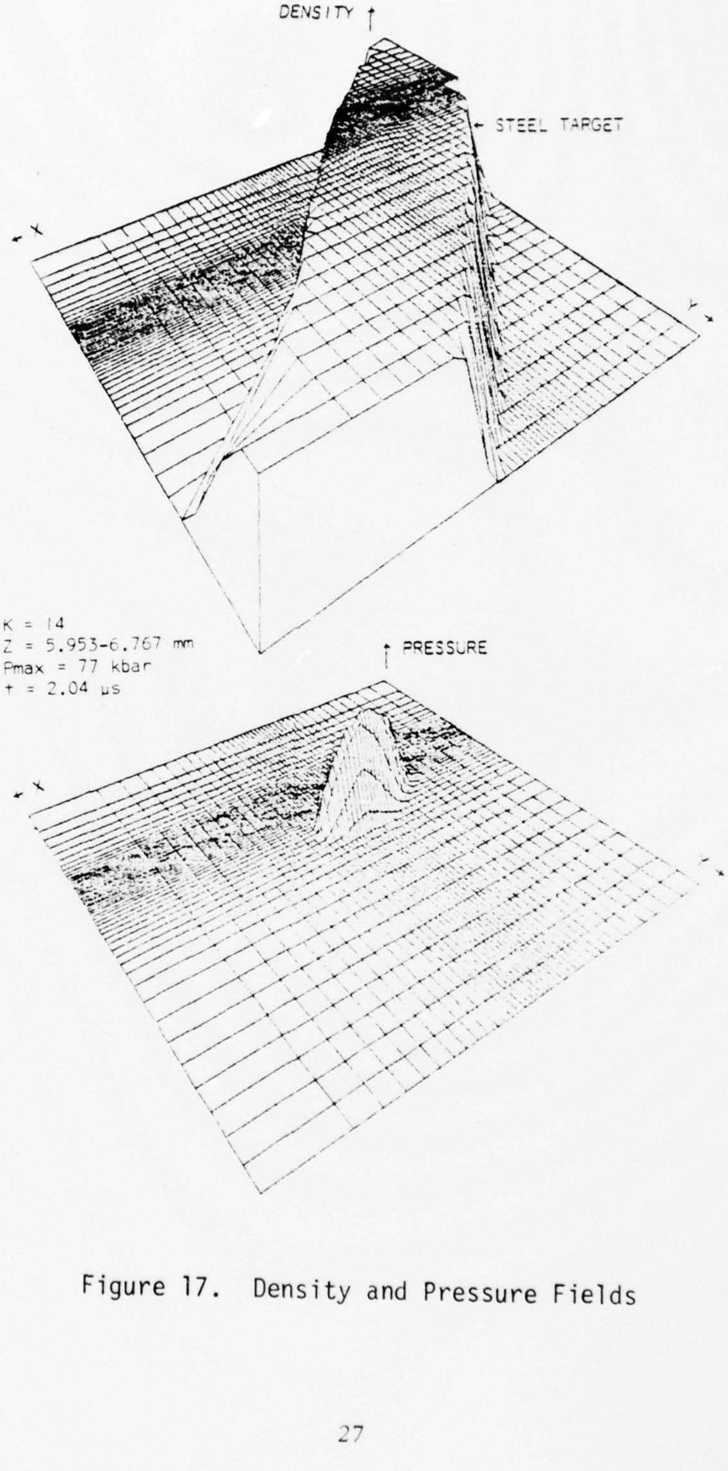

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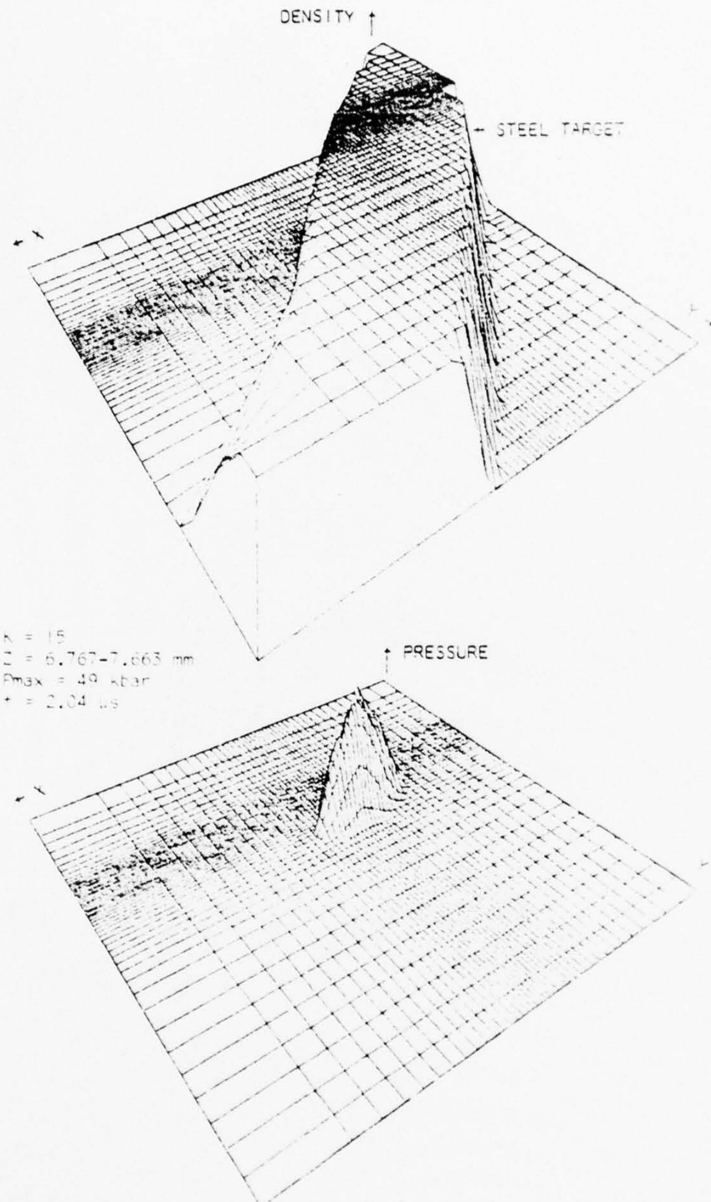

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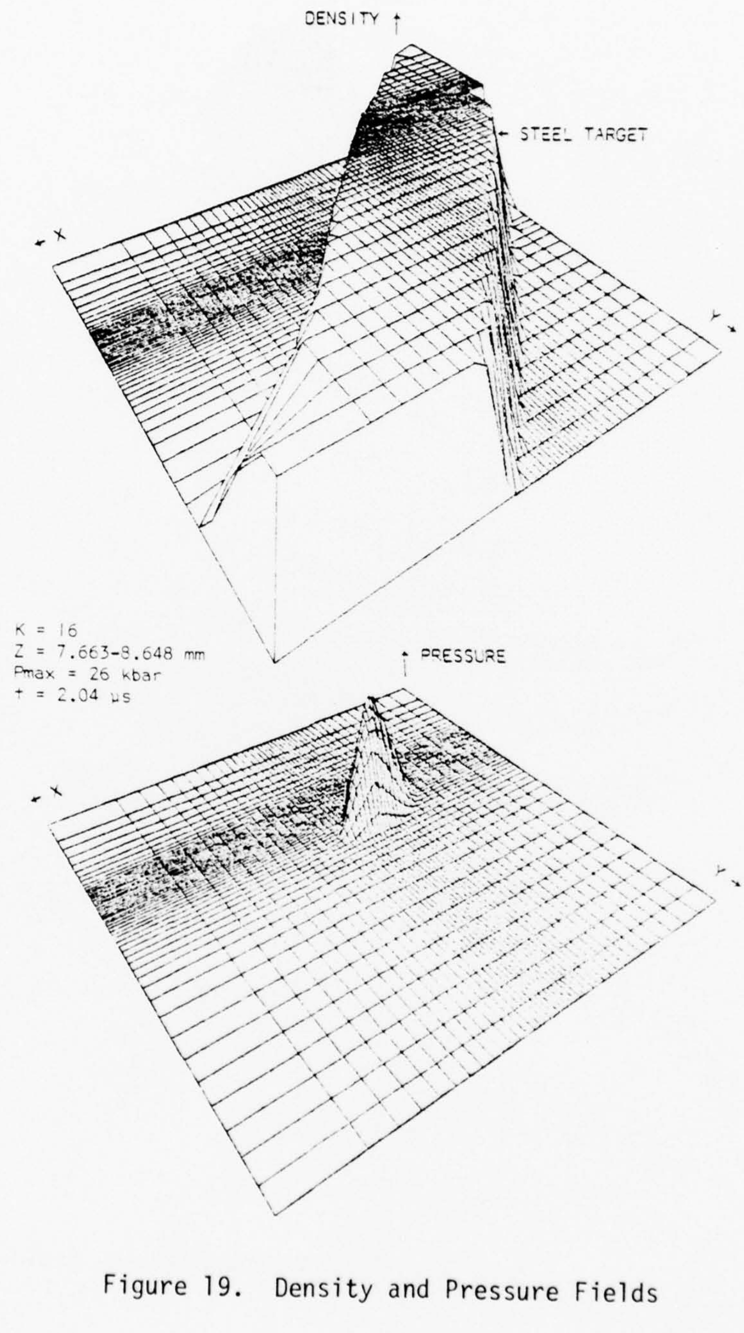

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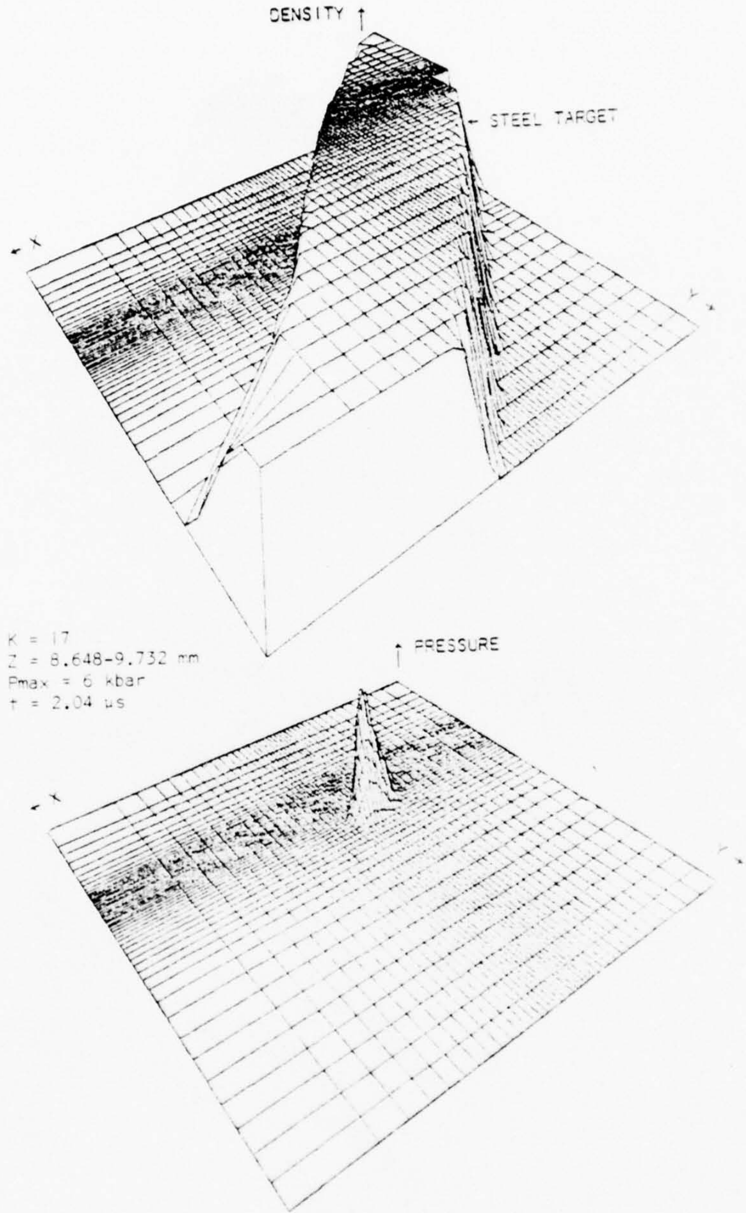

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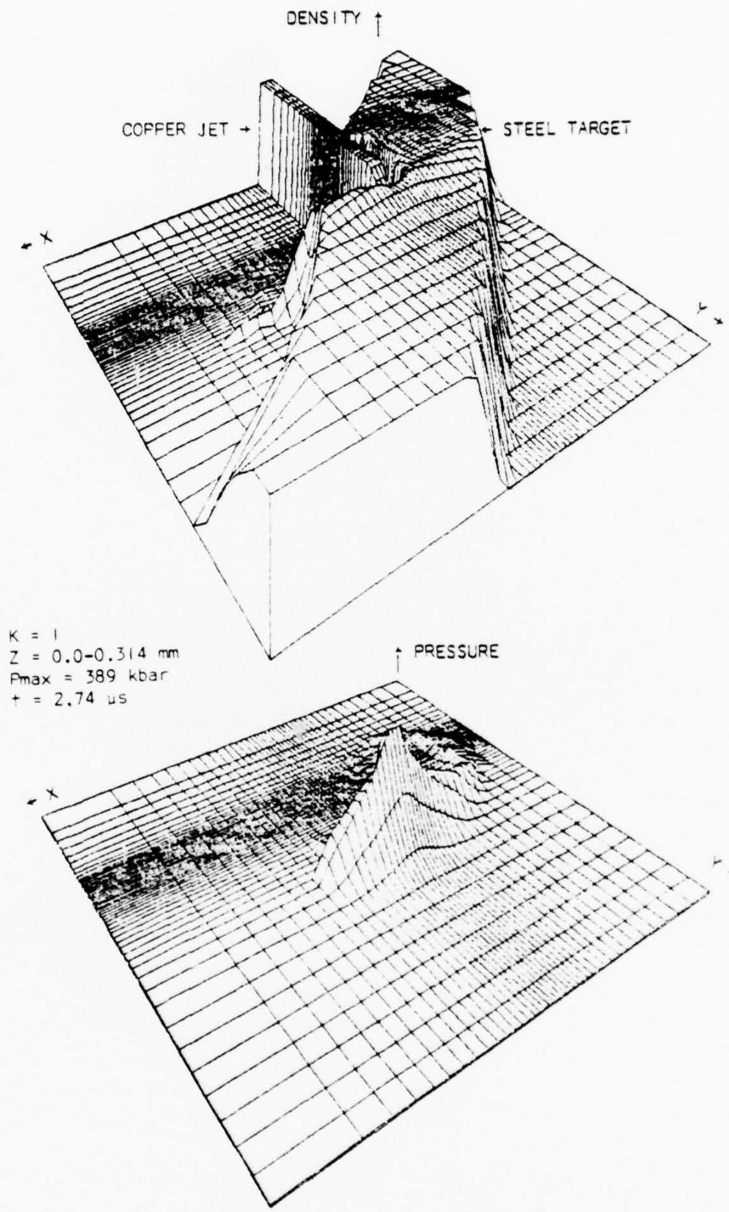

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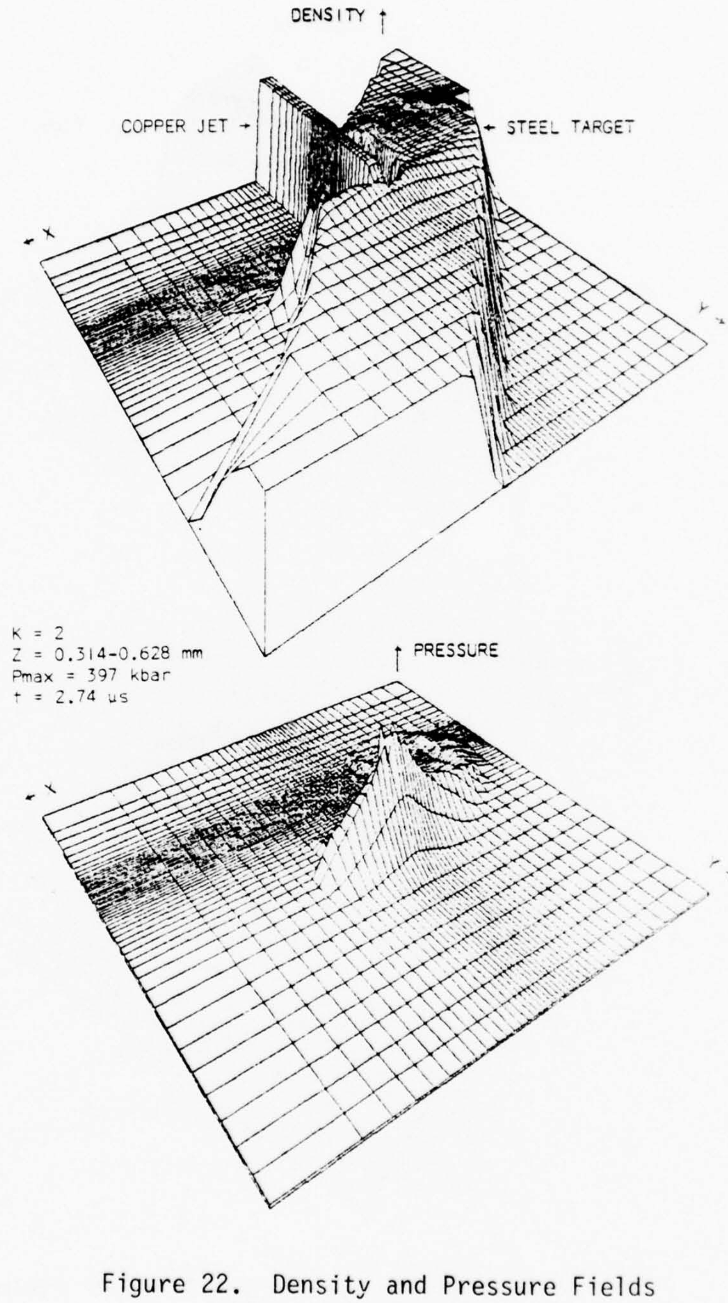

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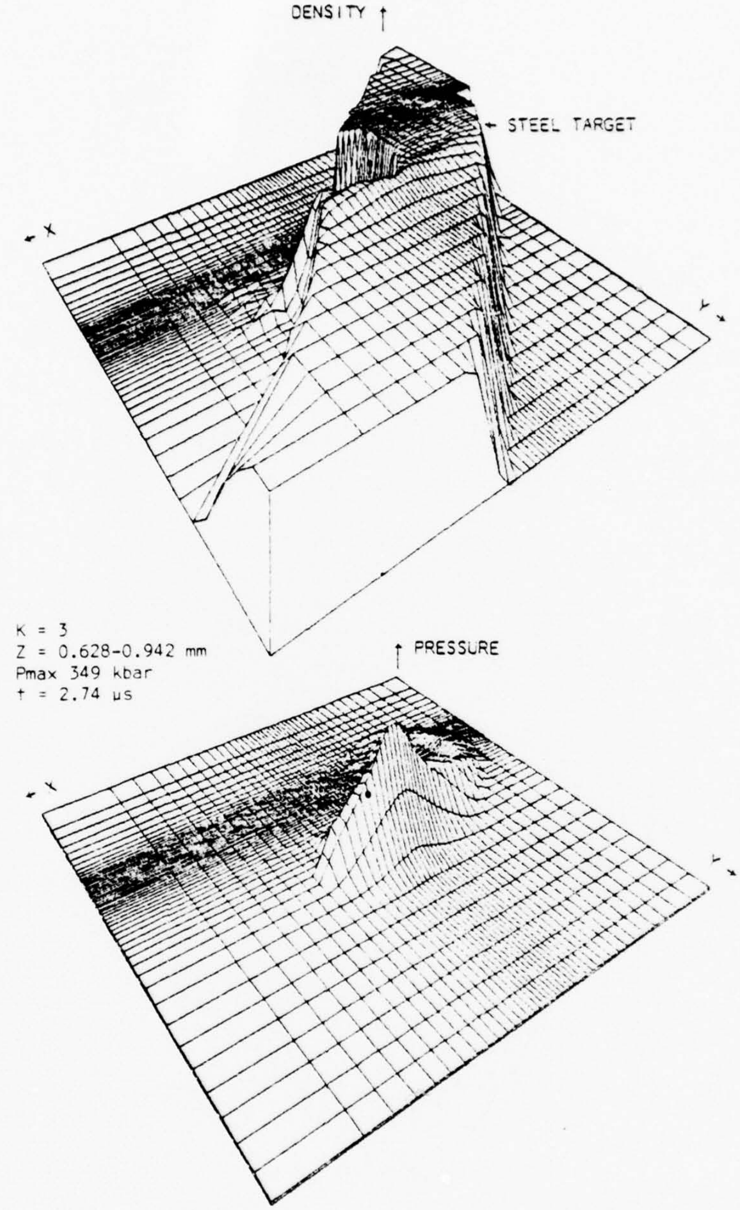

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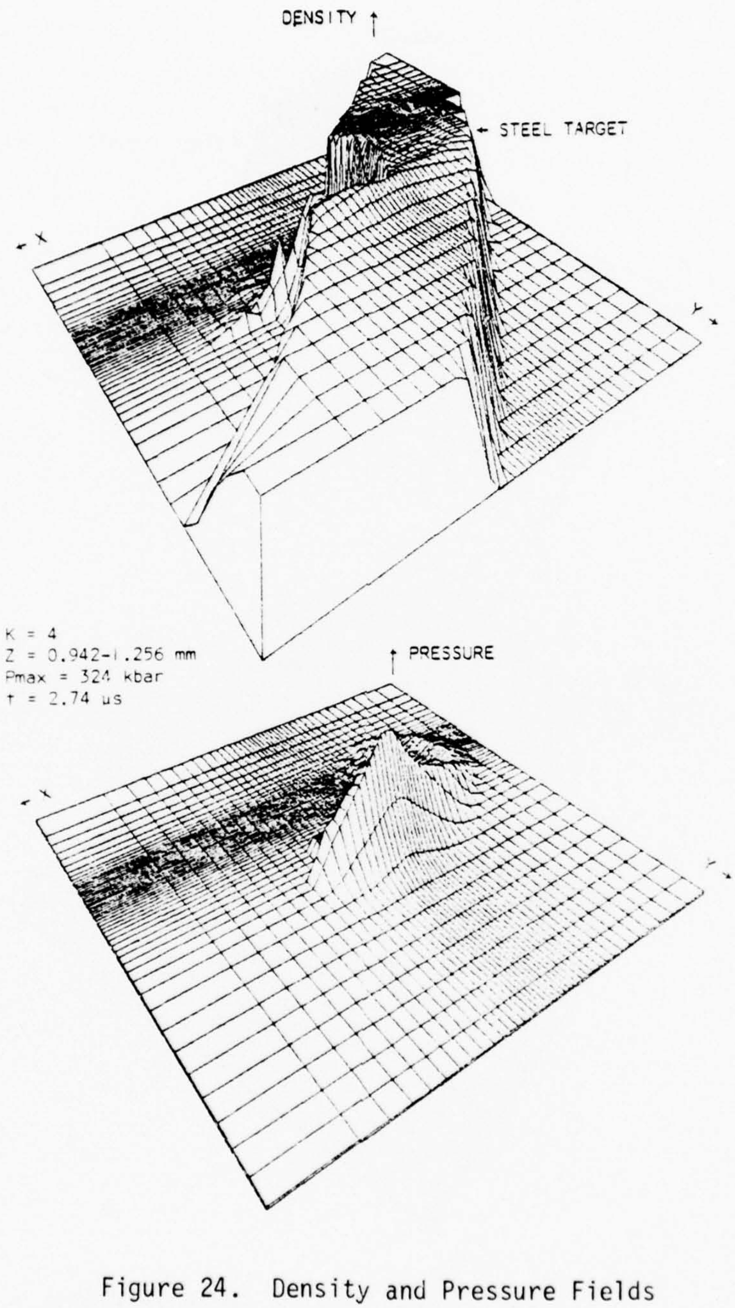

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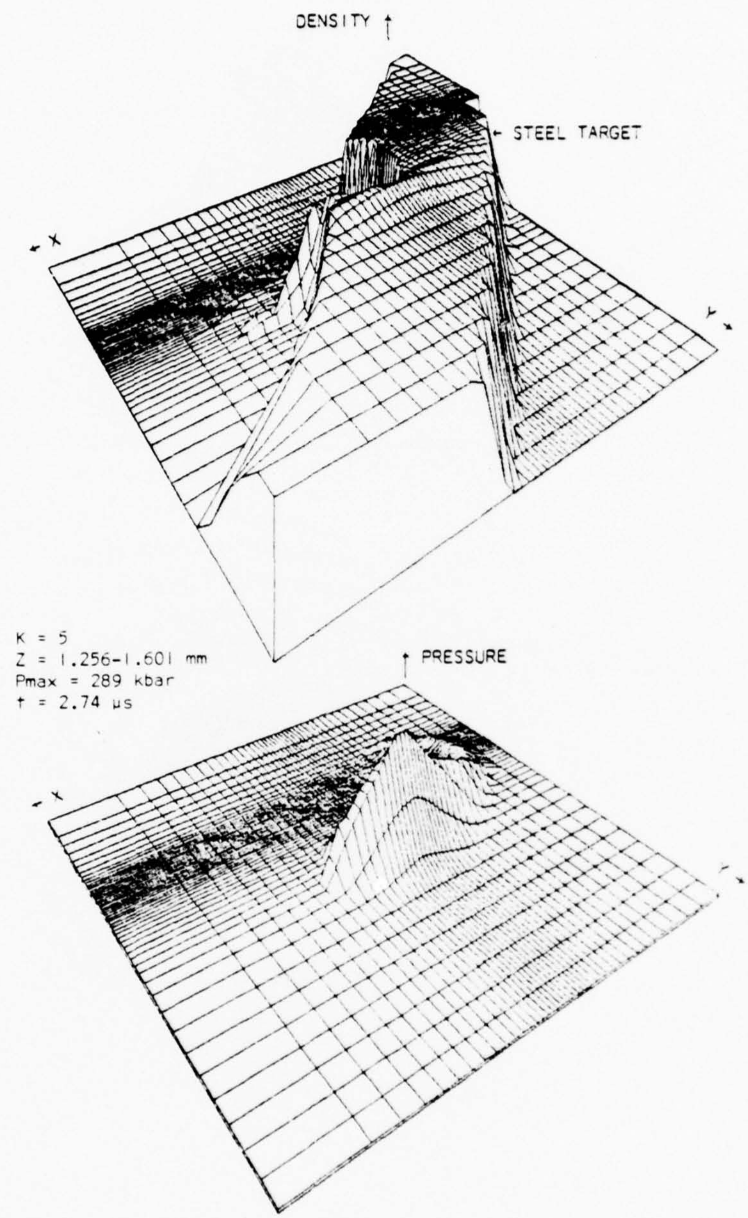

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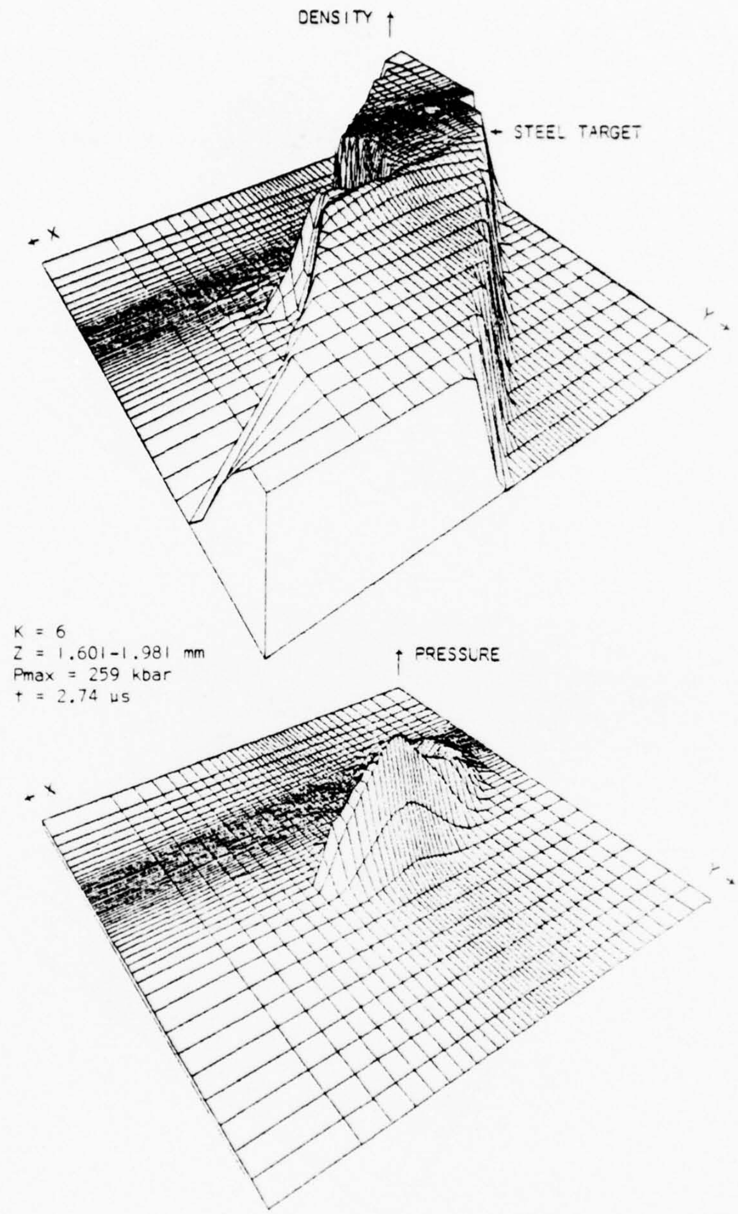

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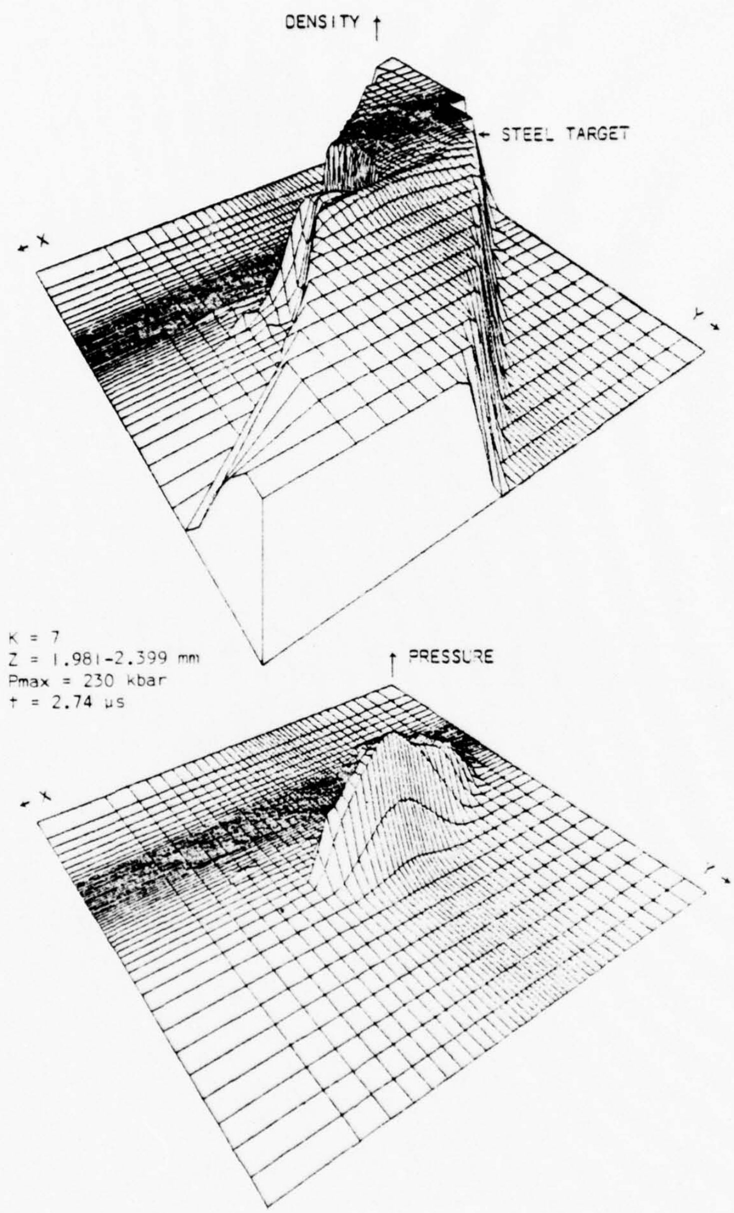

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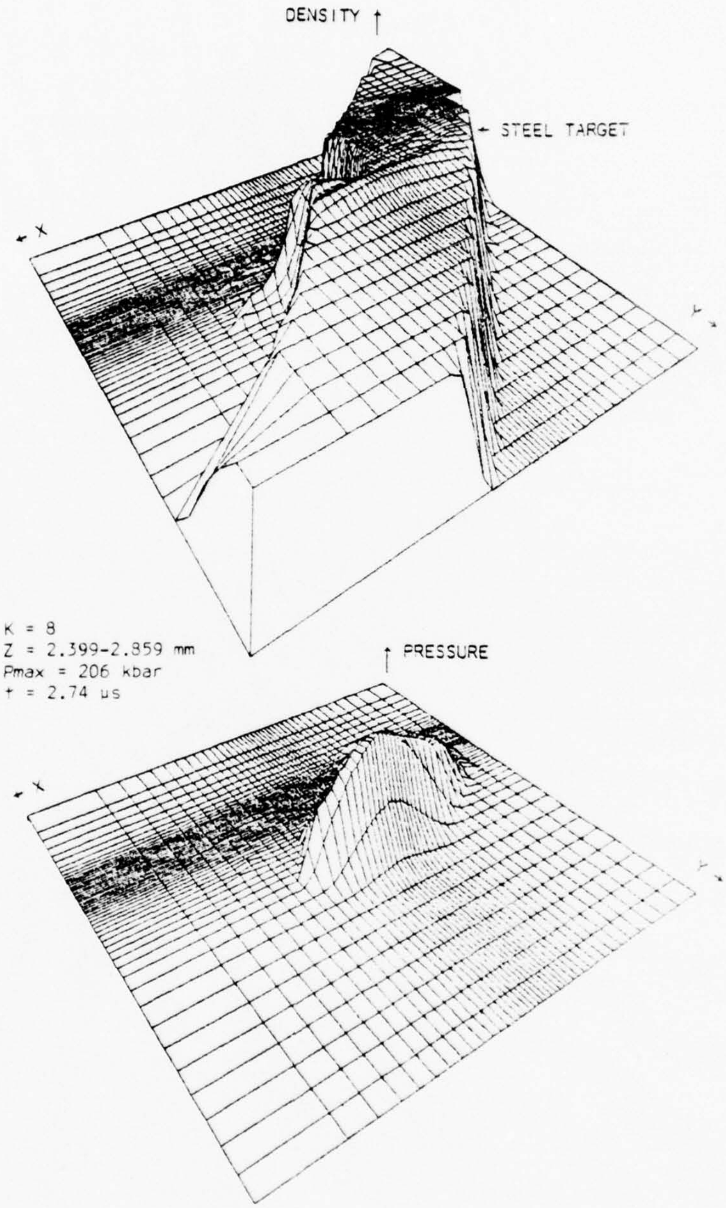

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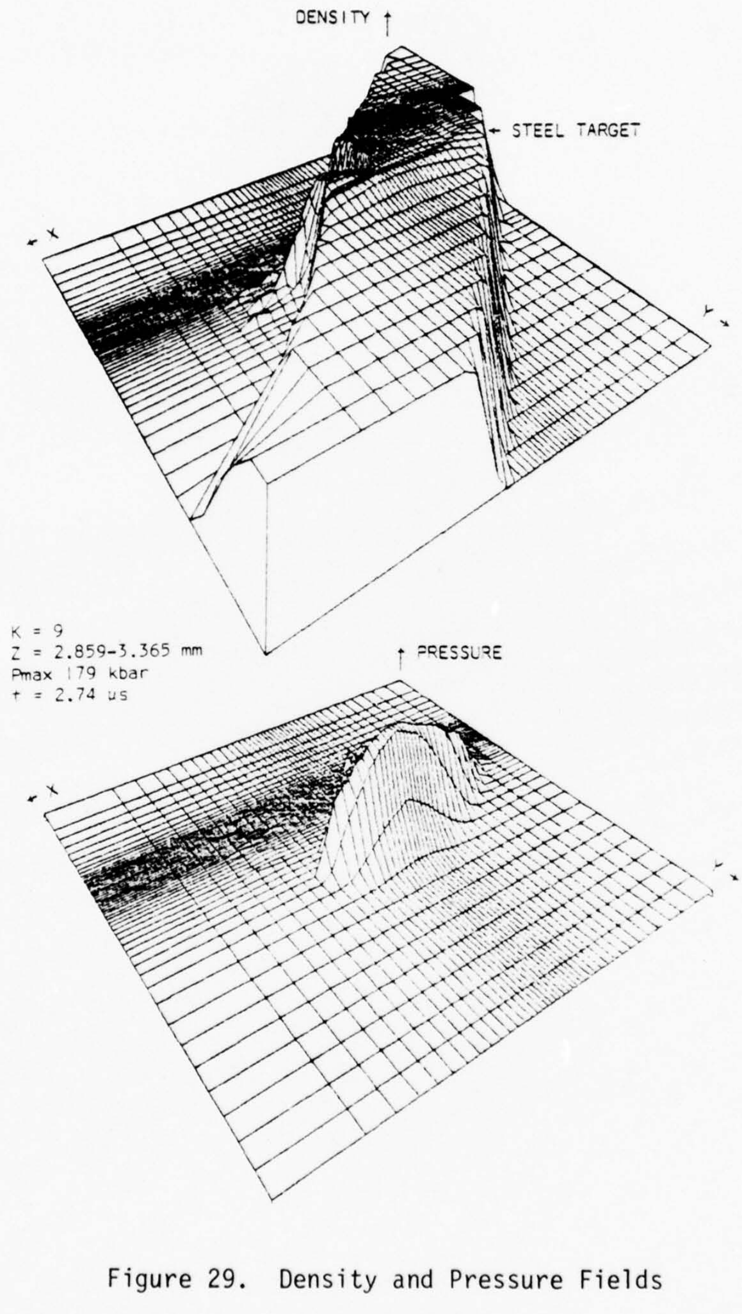

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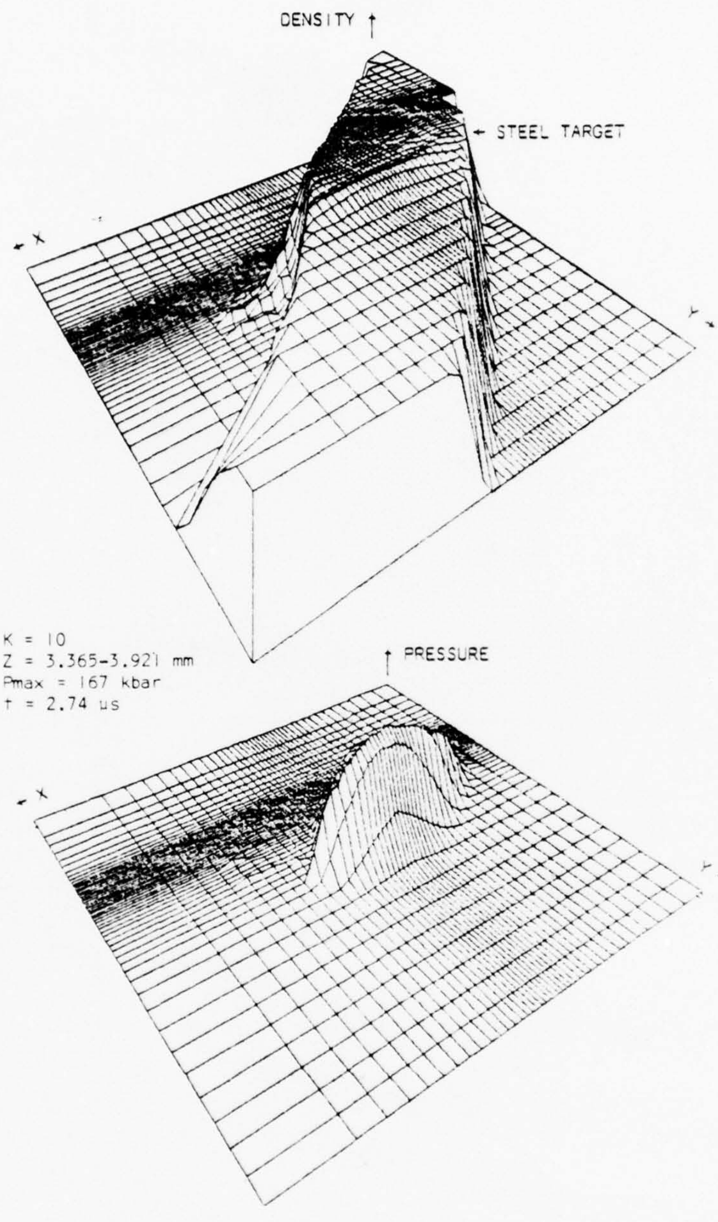

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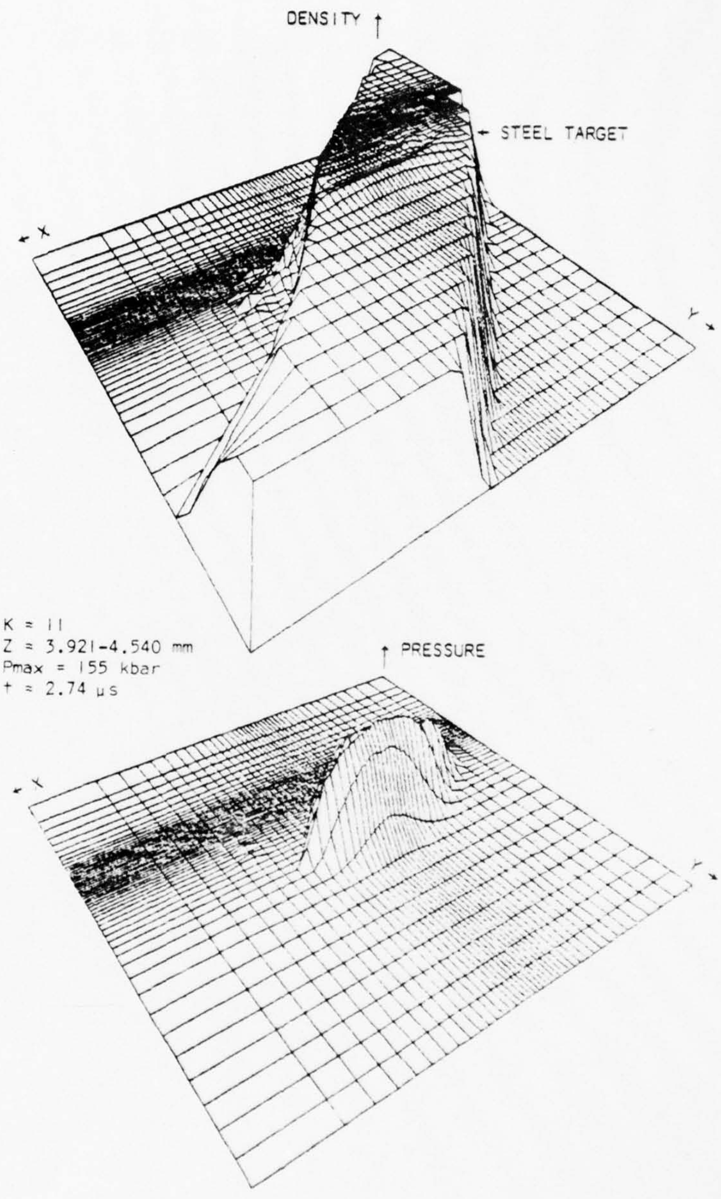

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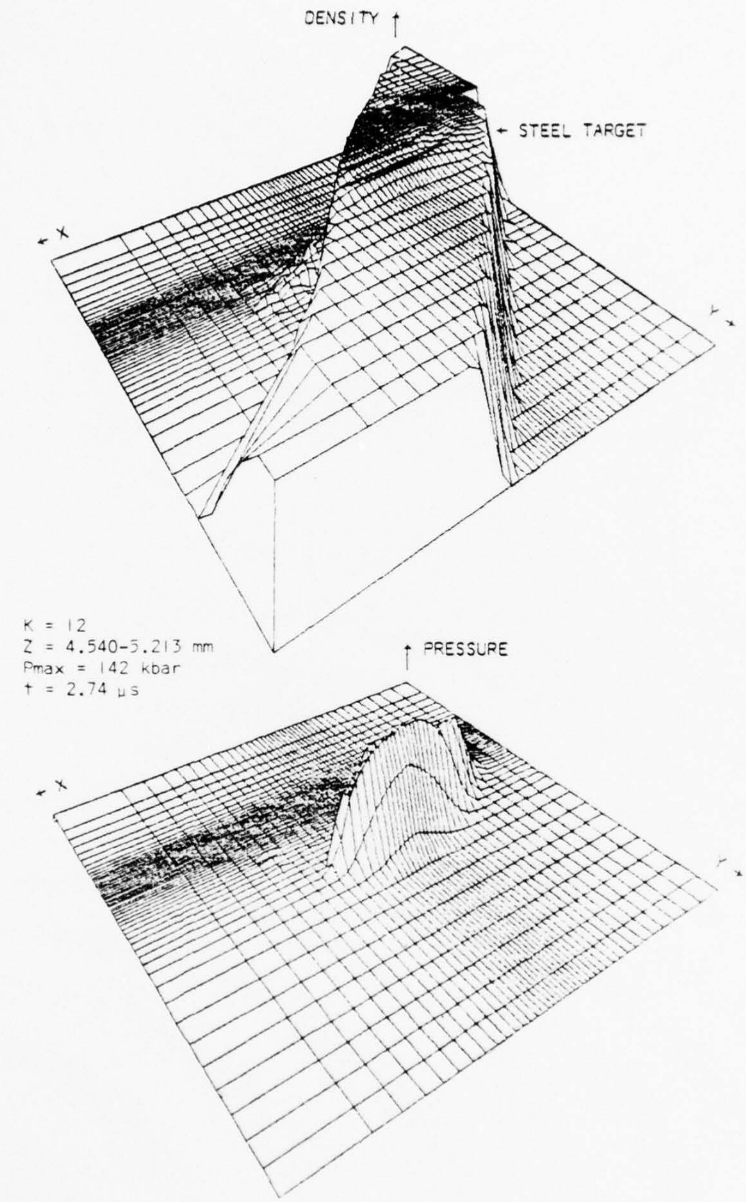

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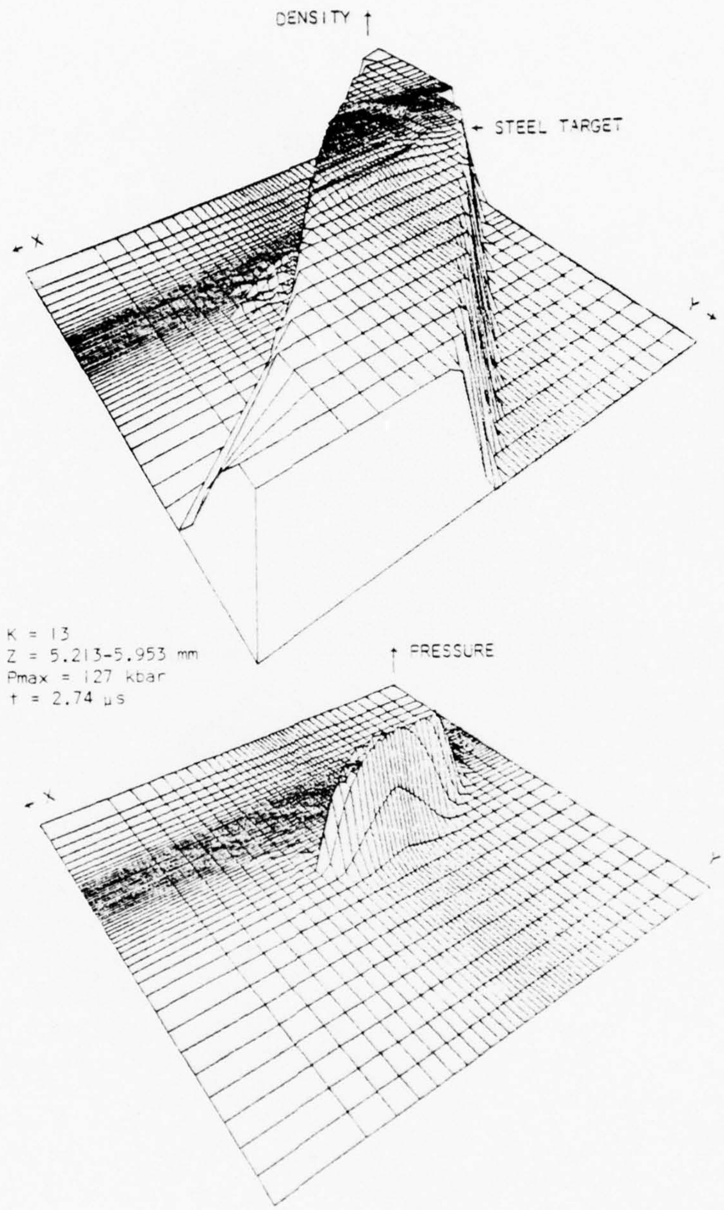

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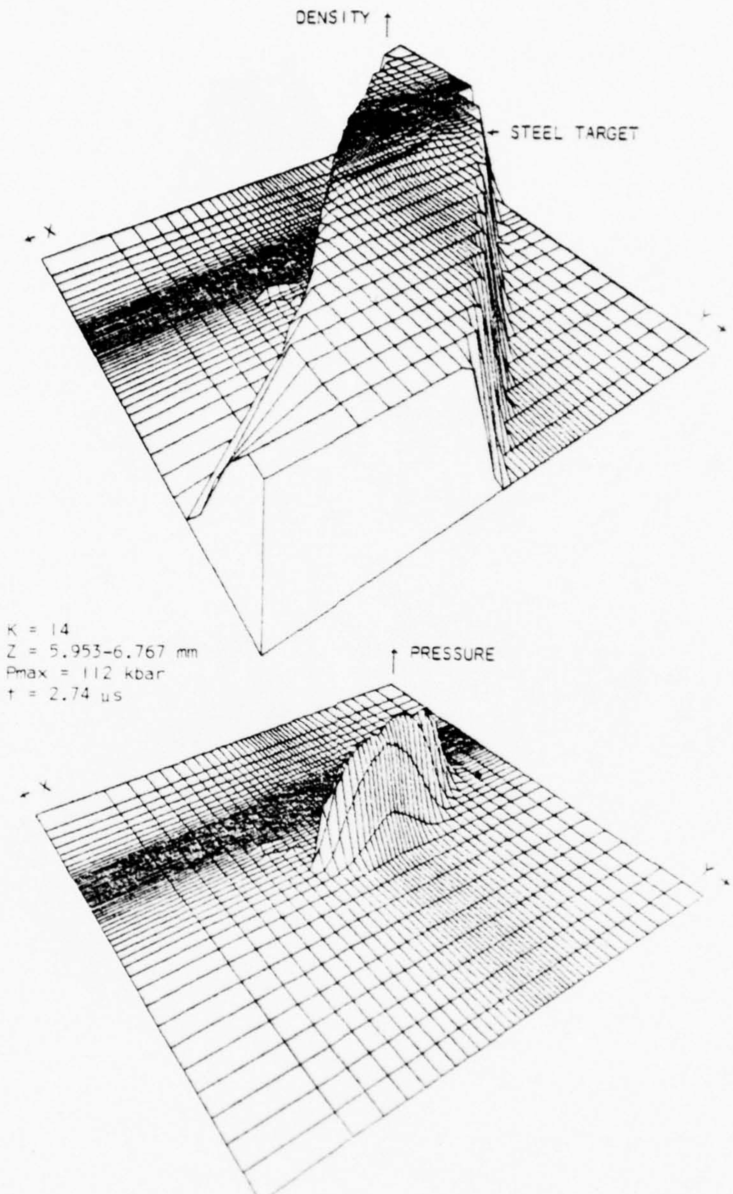

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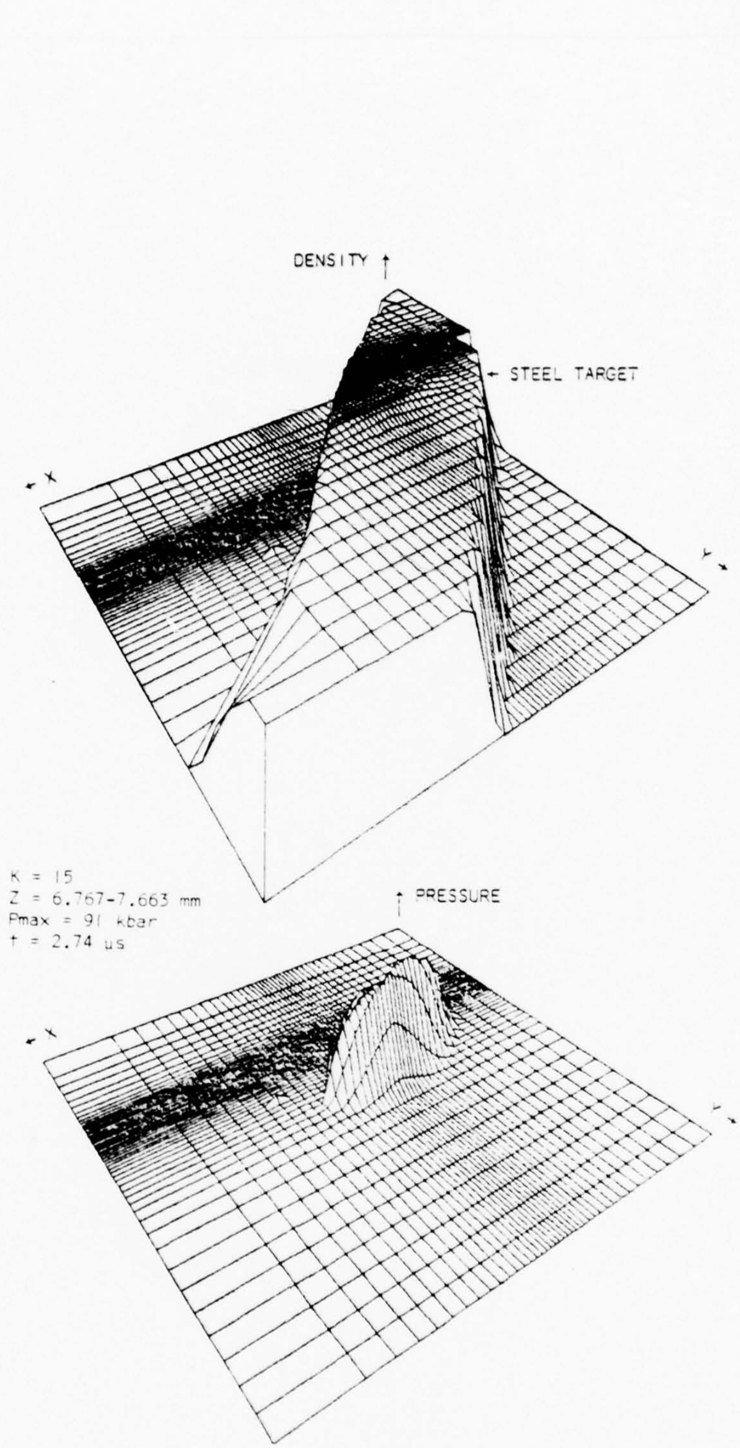

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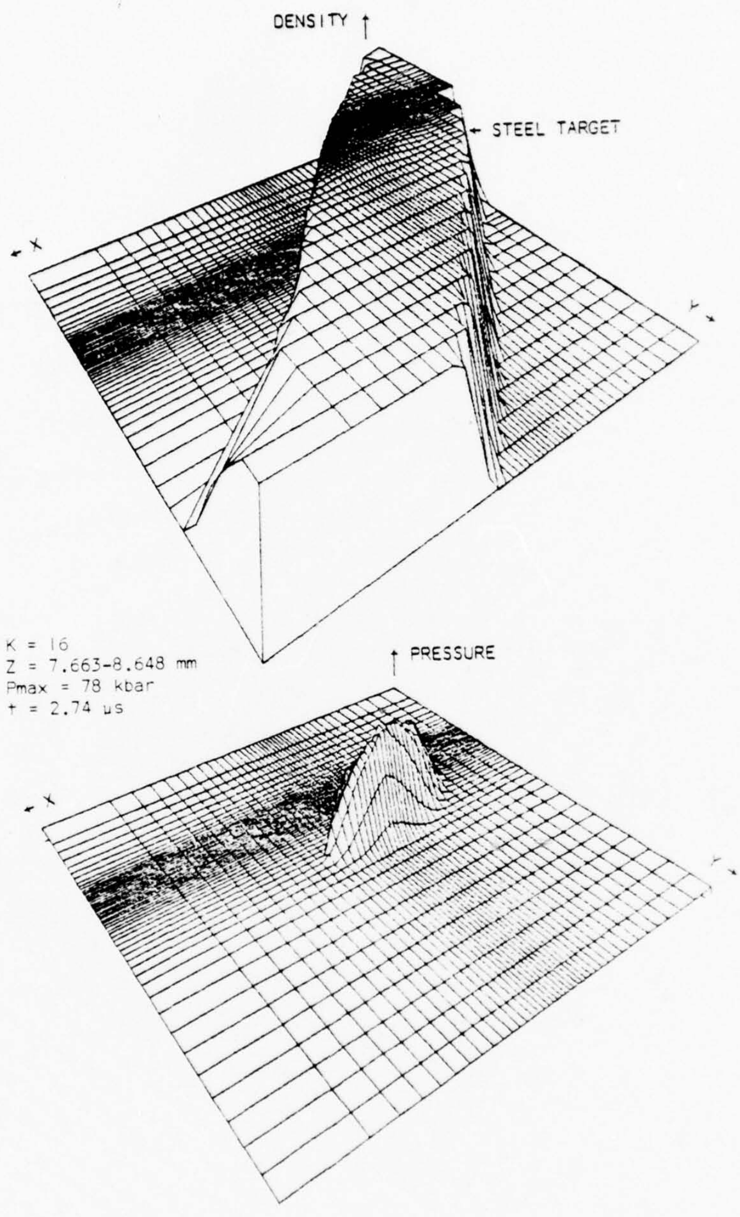

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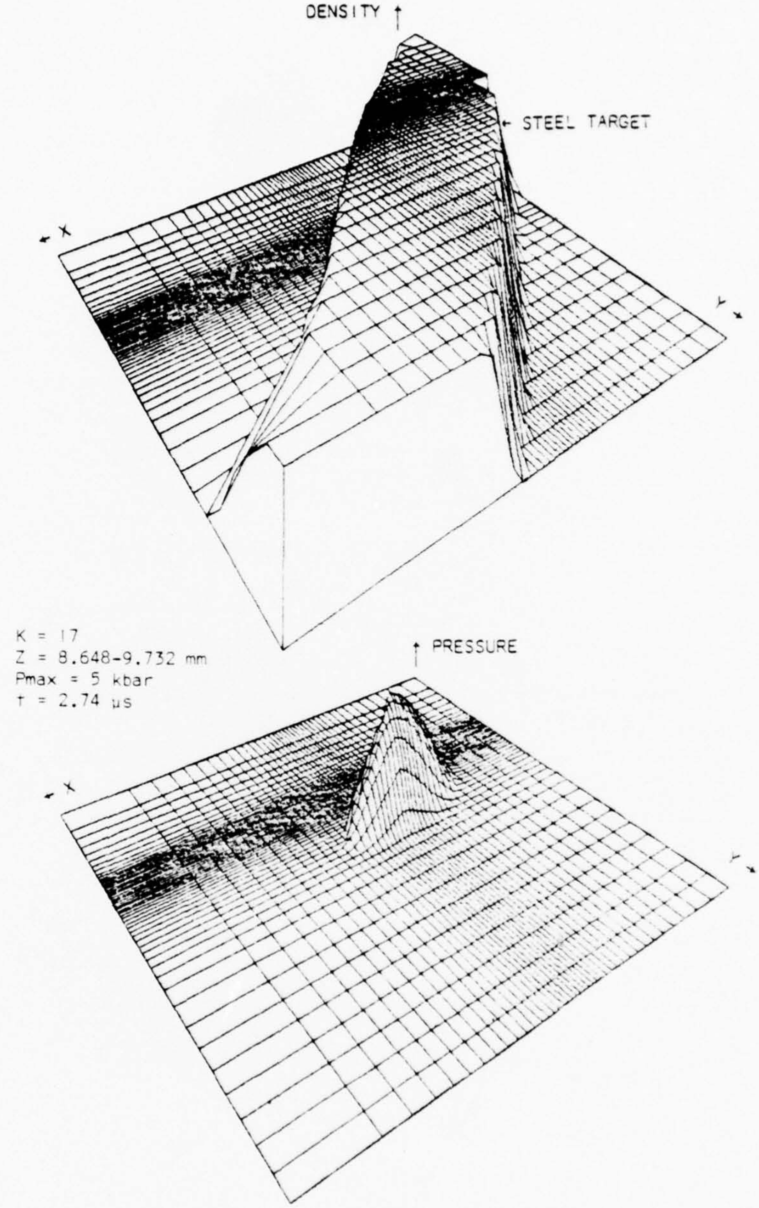
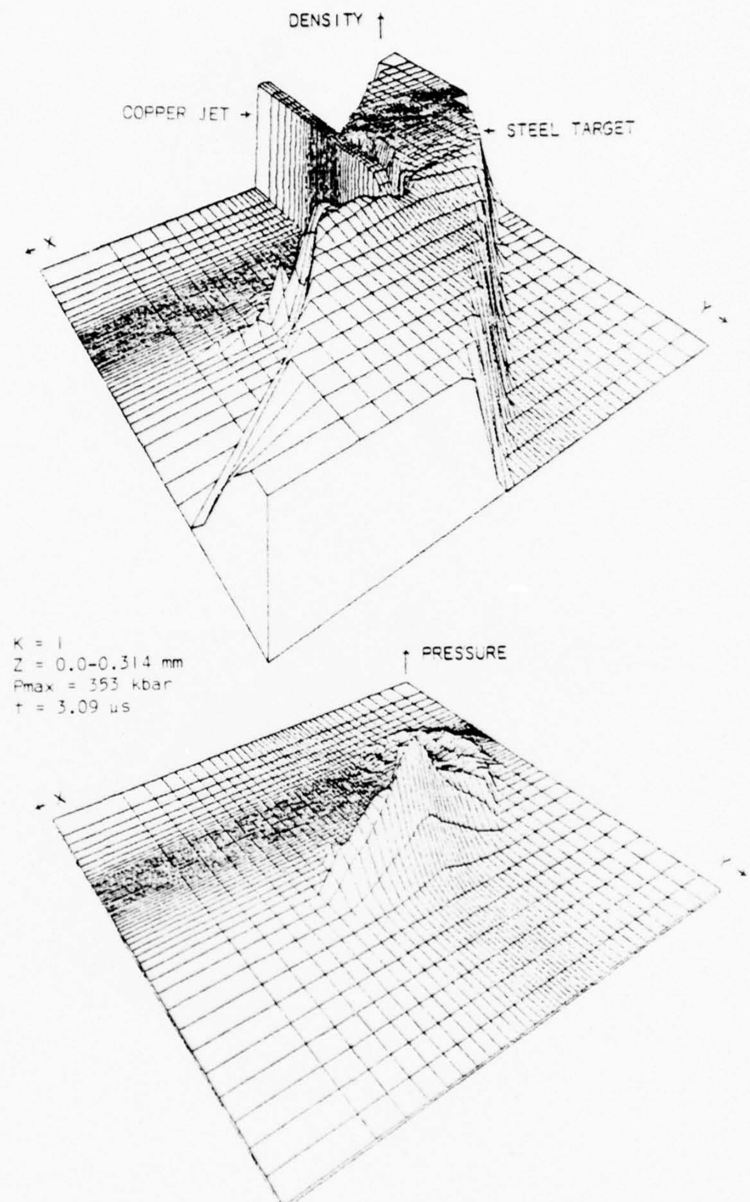


Figure 37. Density and Pressure Fields



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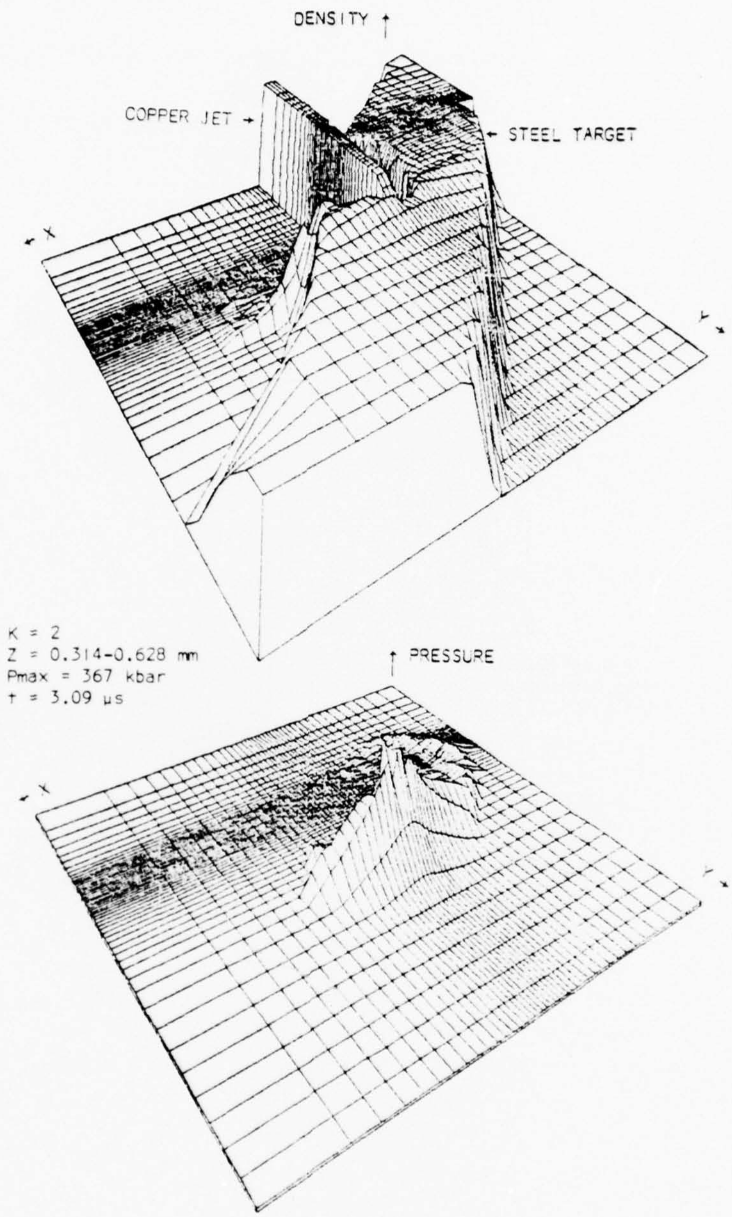

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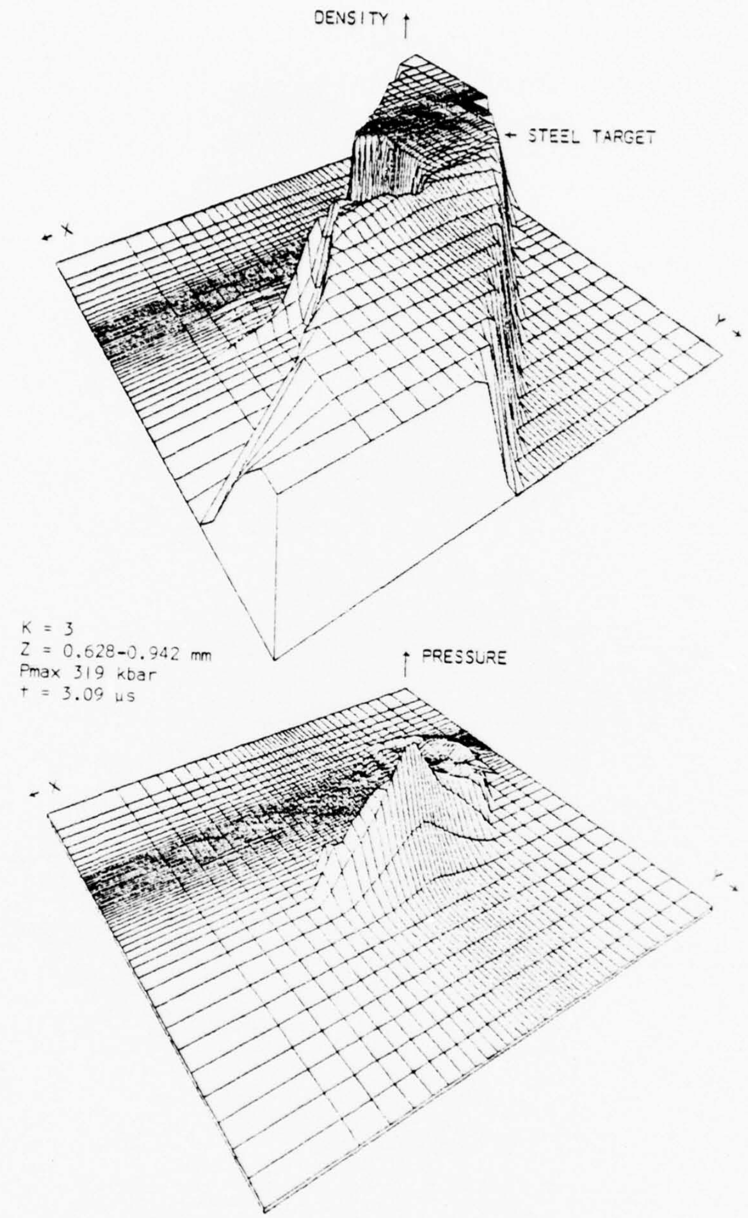

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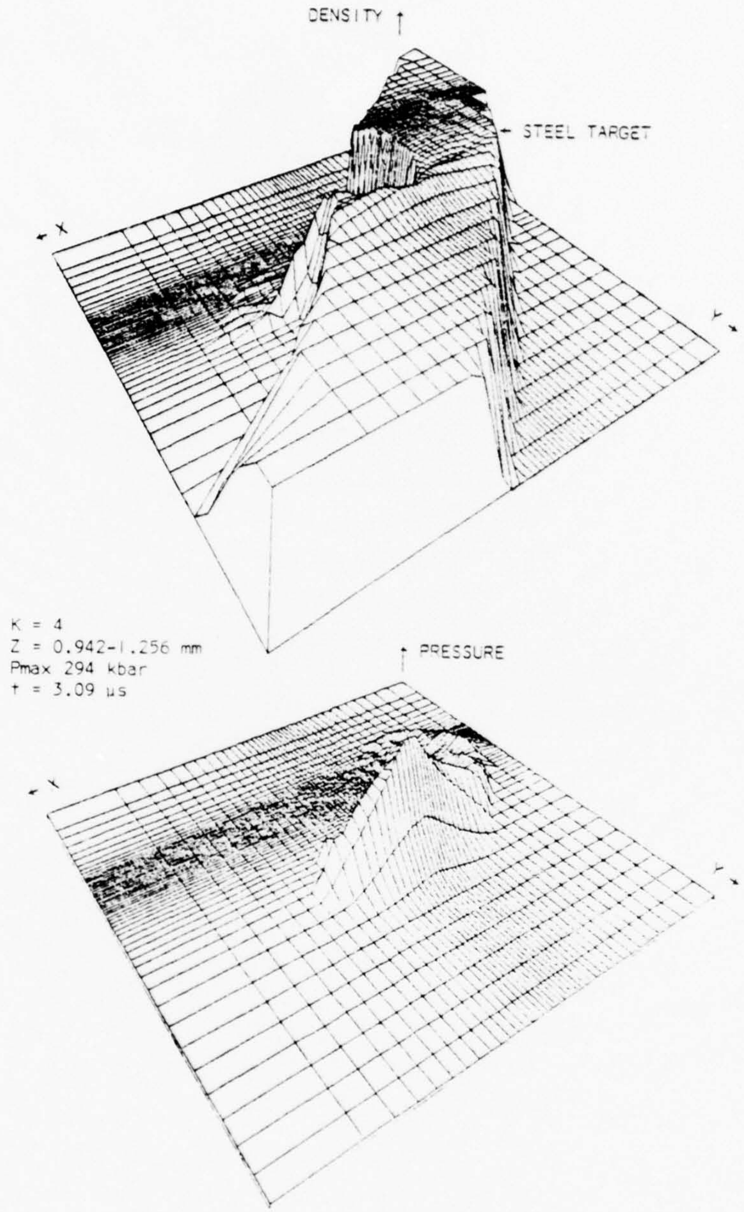

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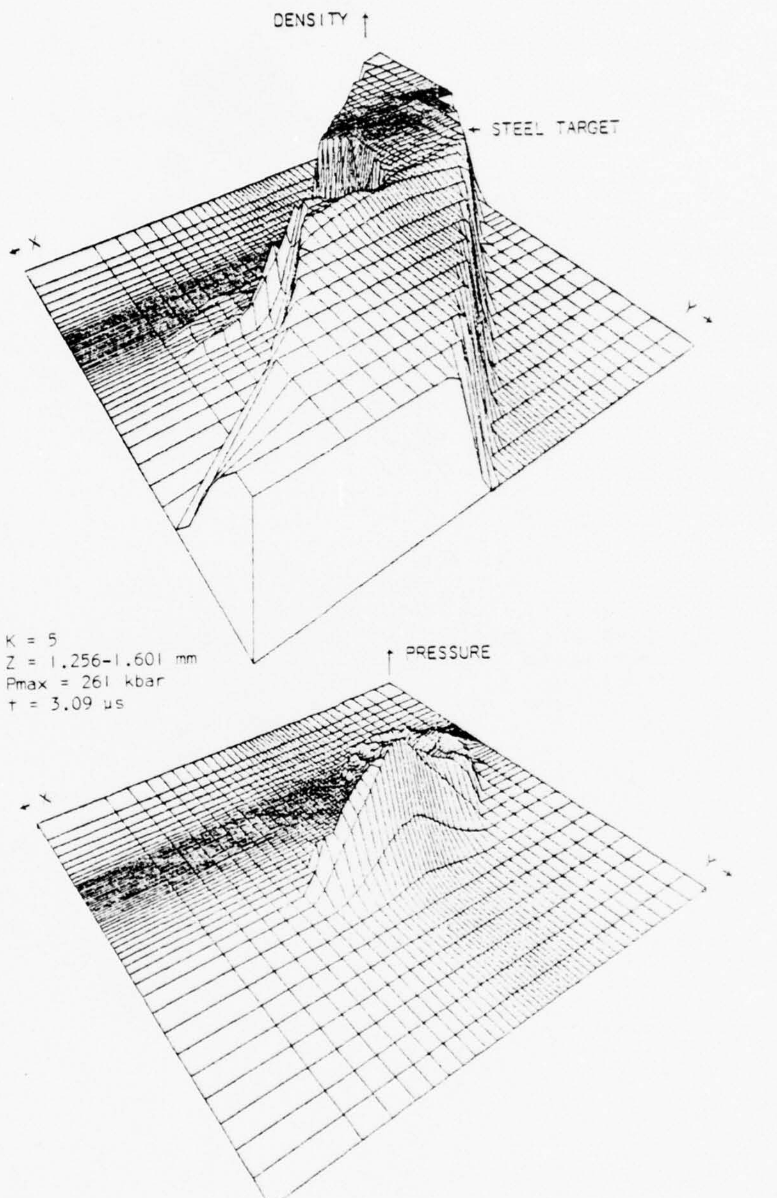

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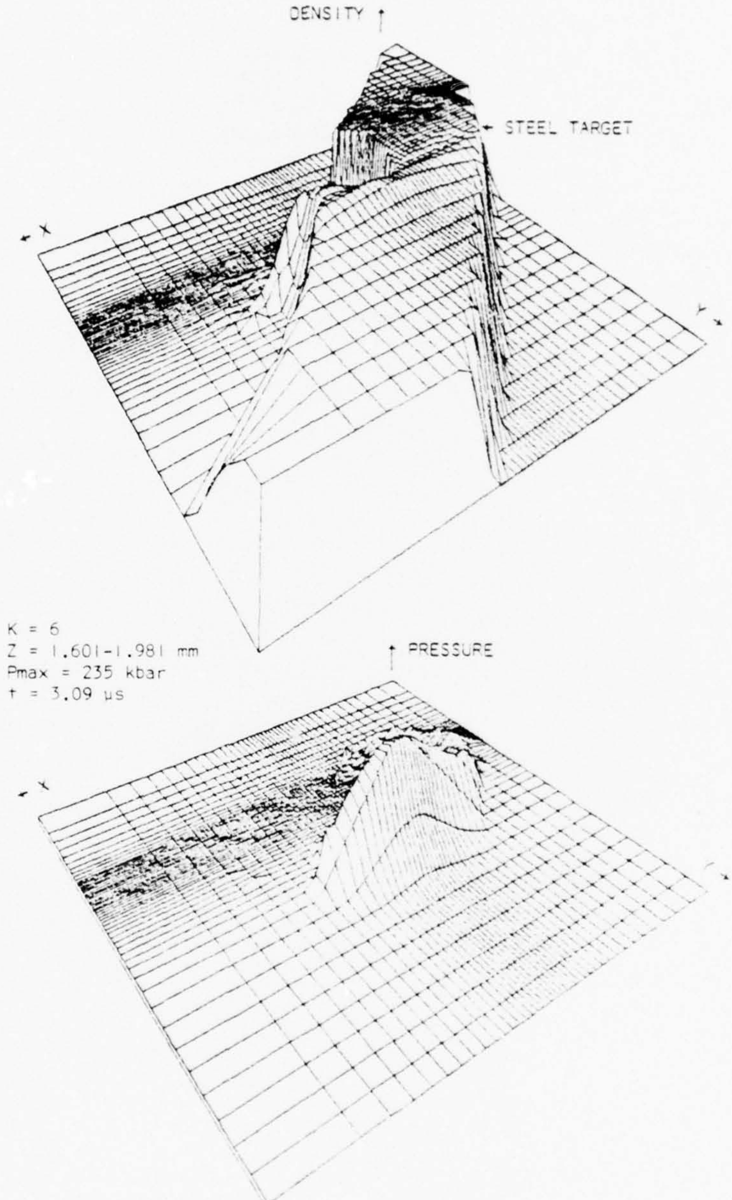

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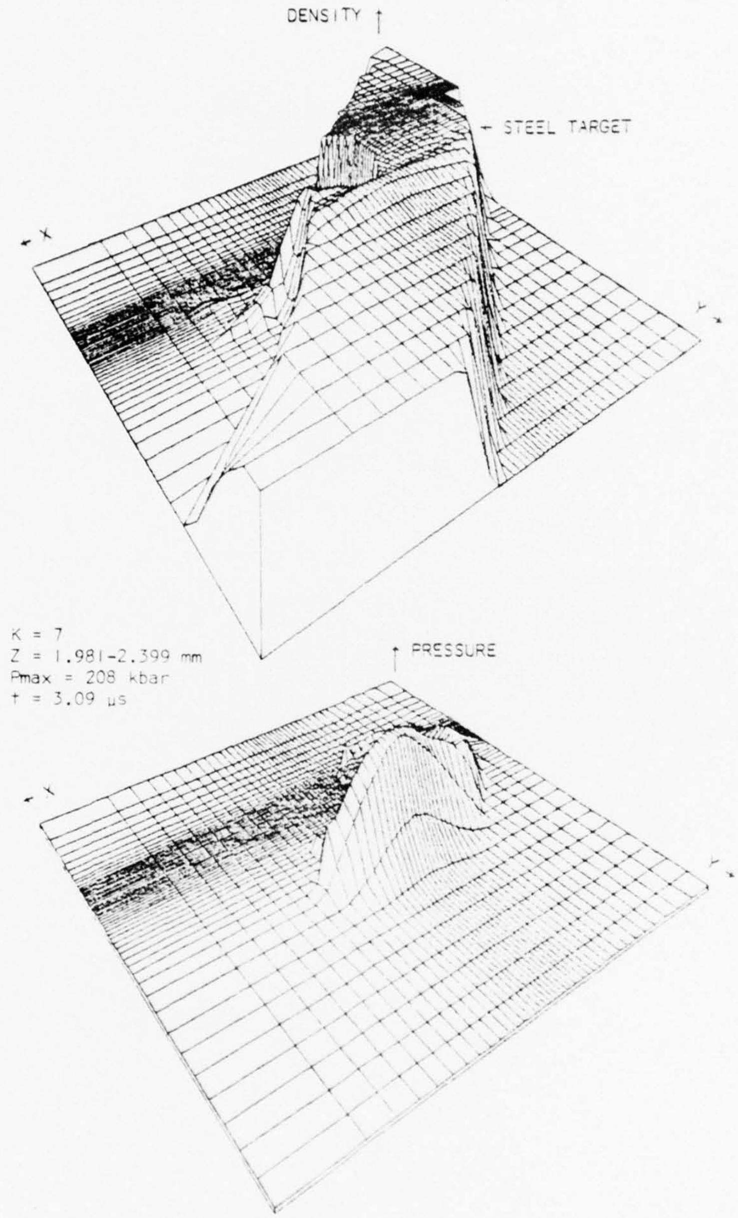

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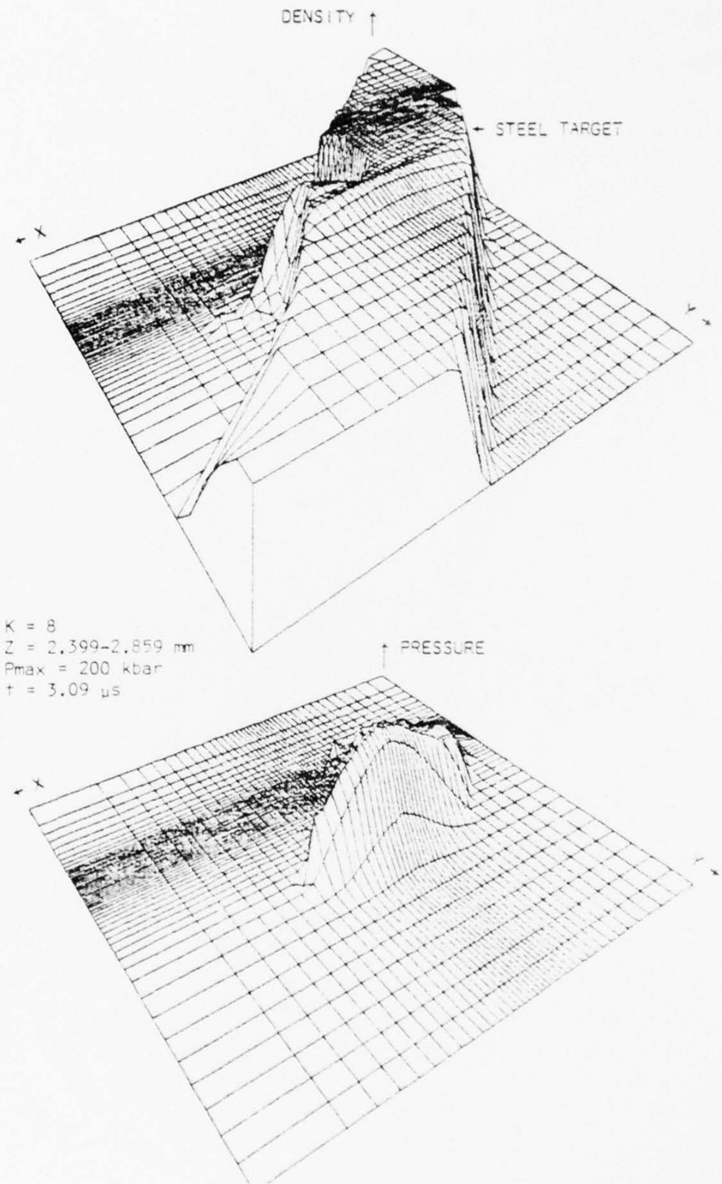

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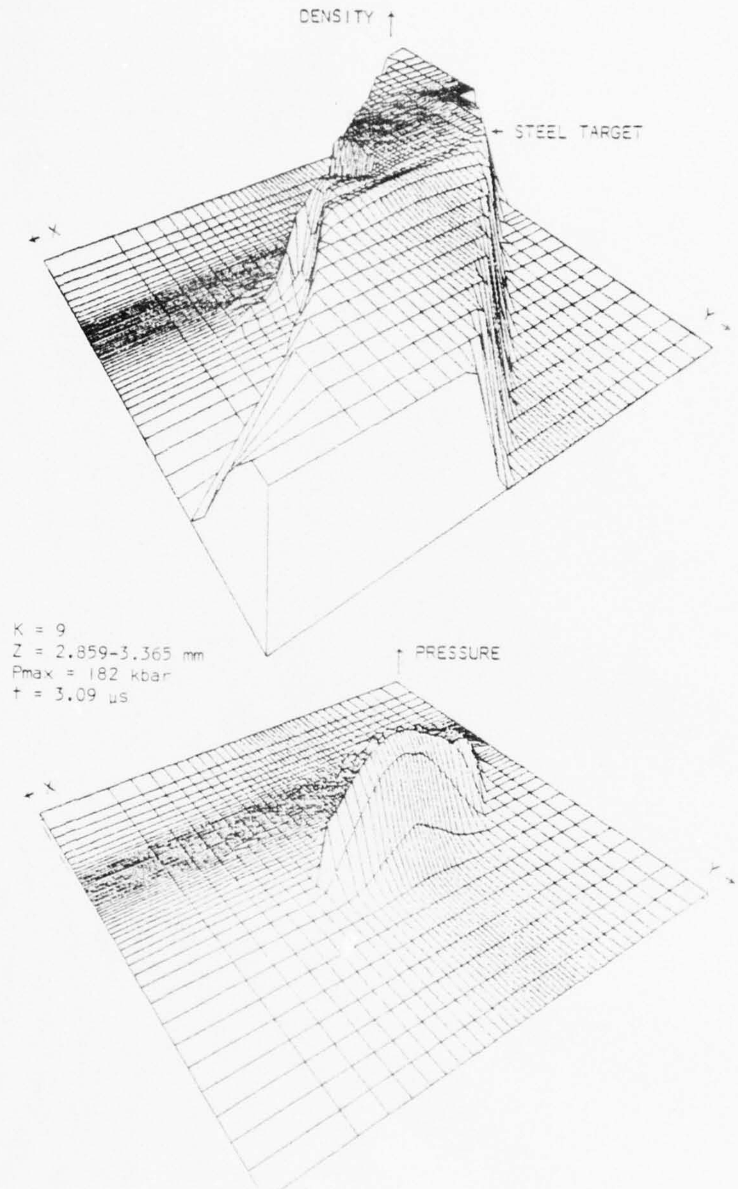

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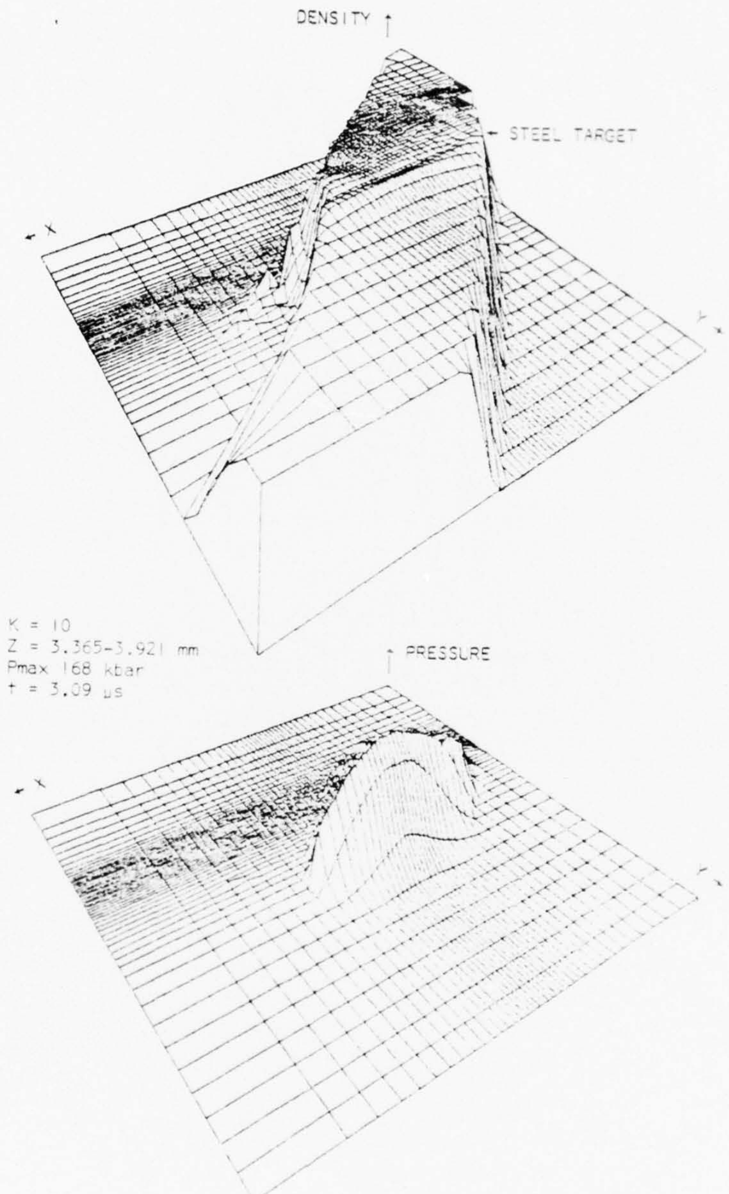

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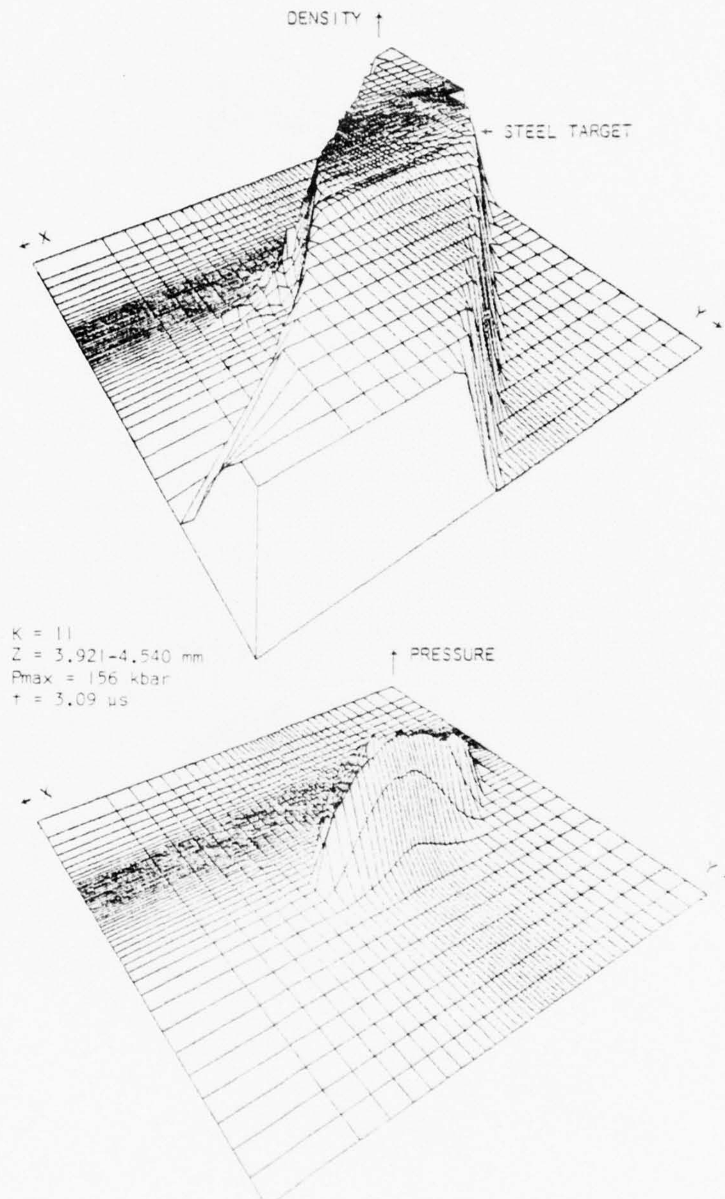

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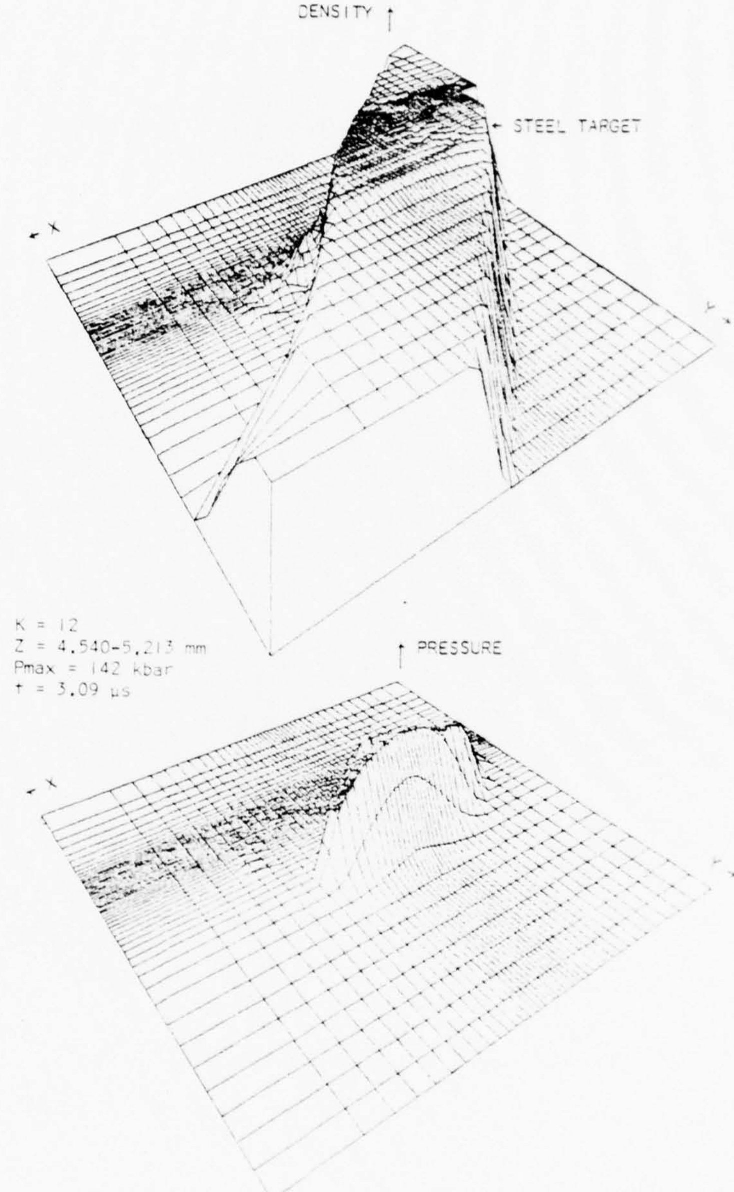

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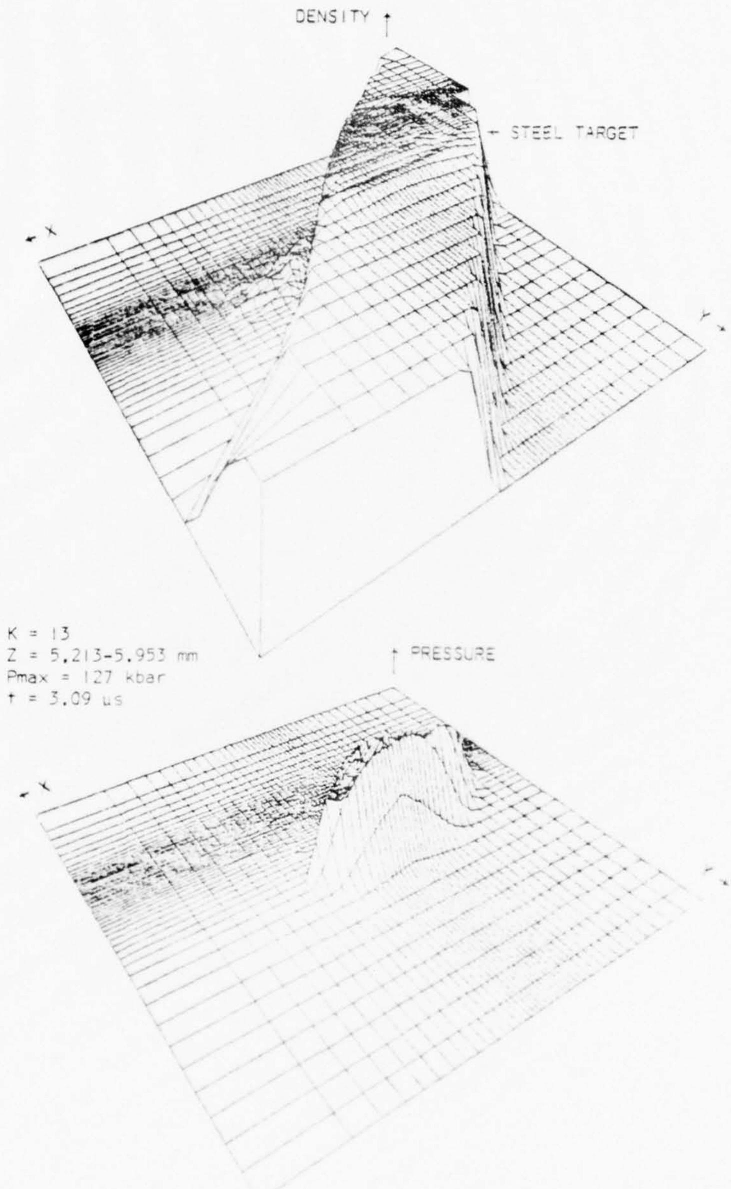

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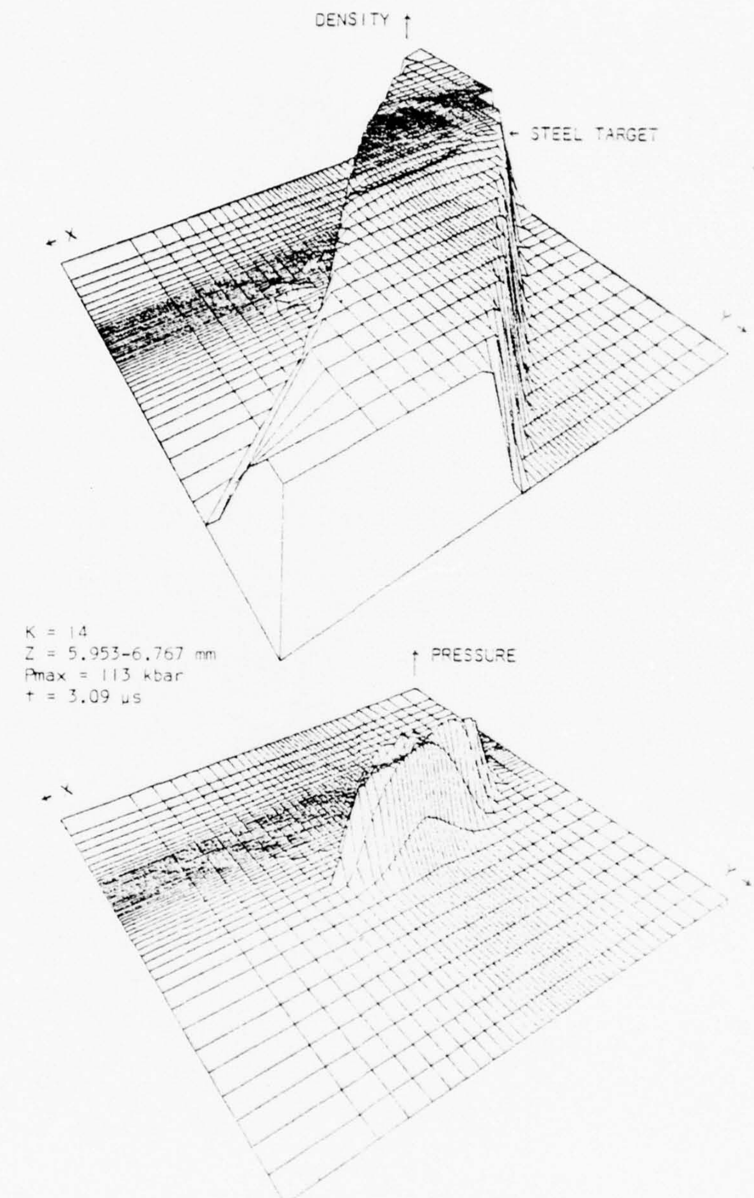

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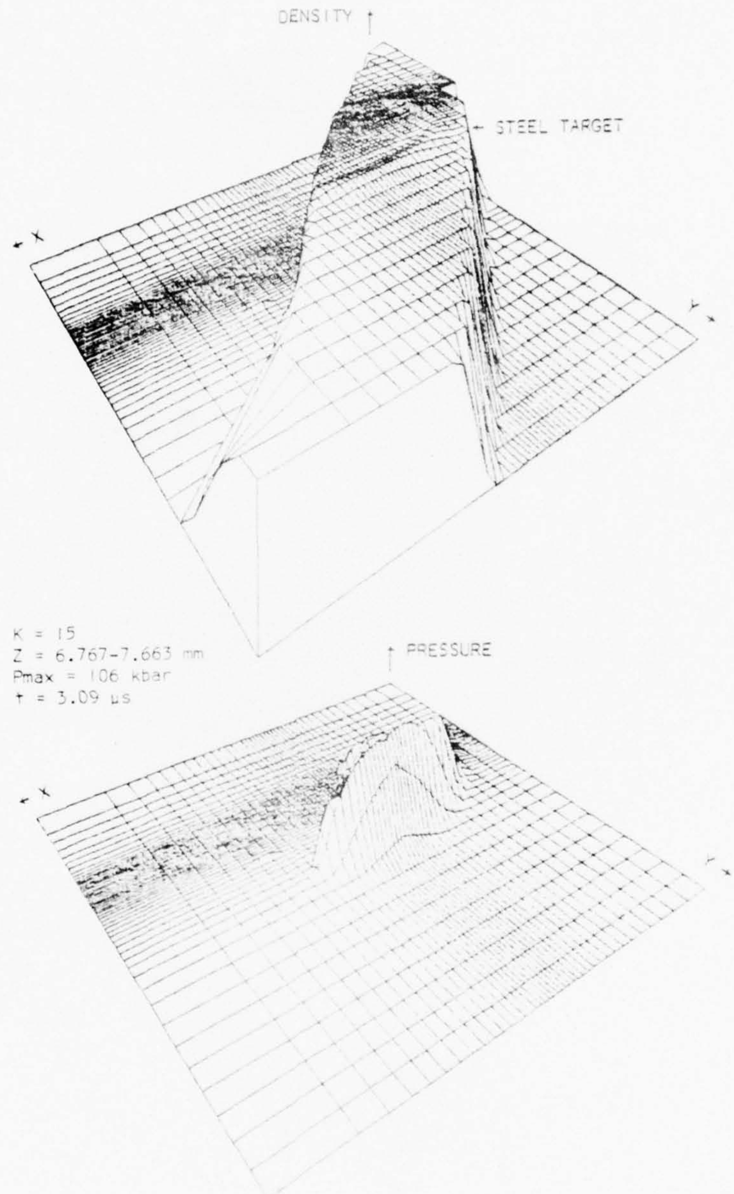

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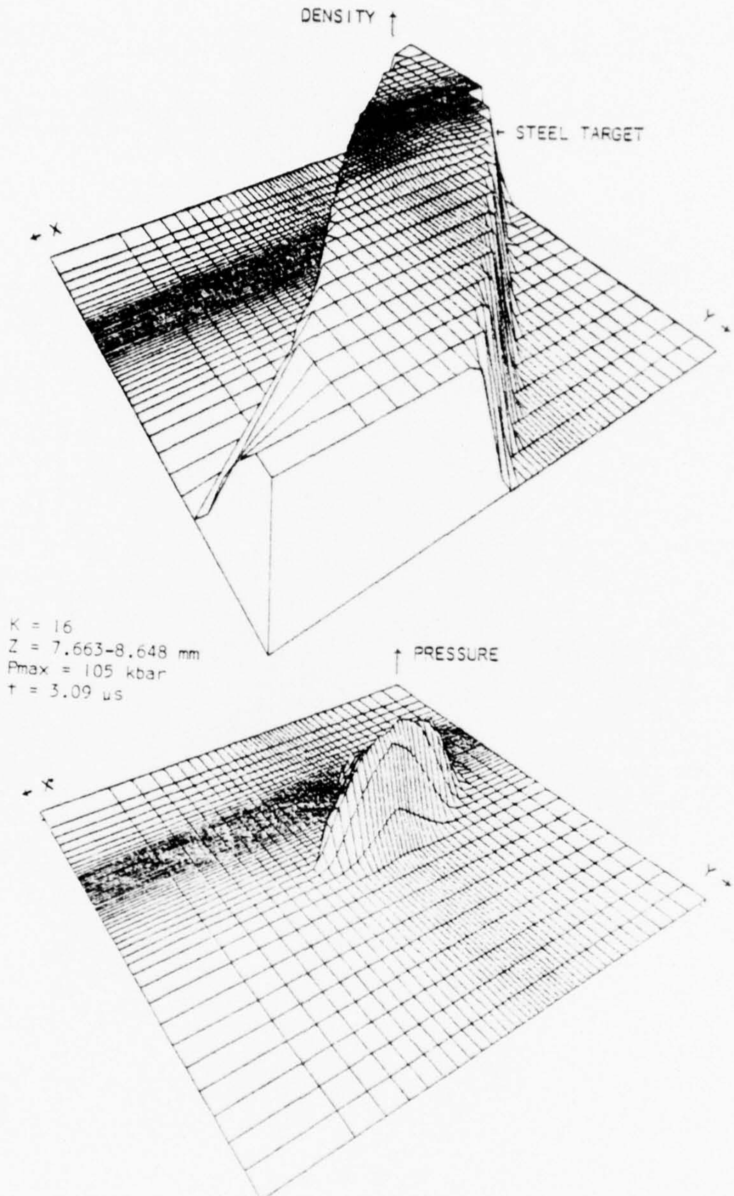

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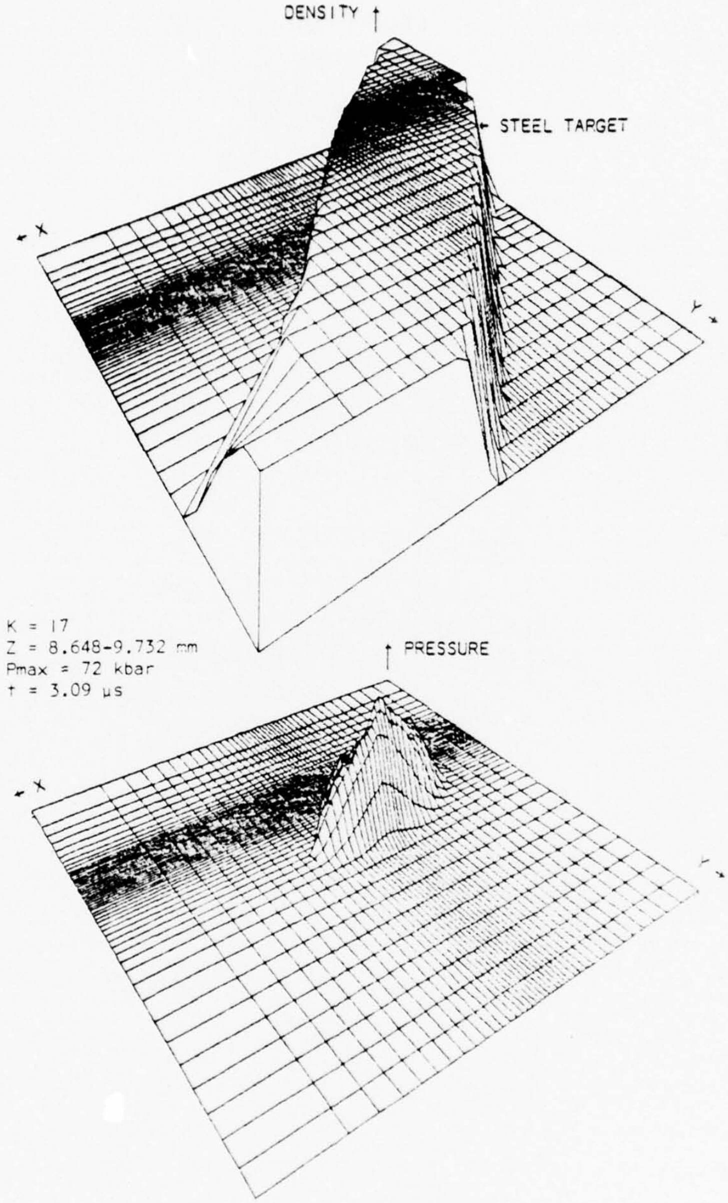

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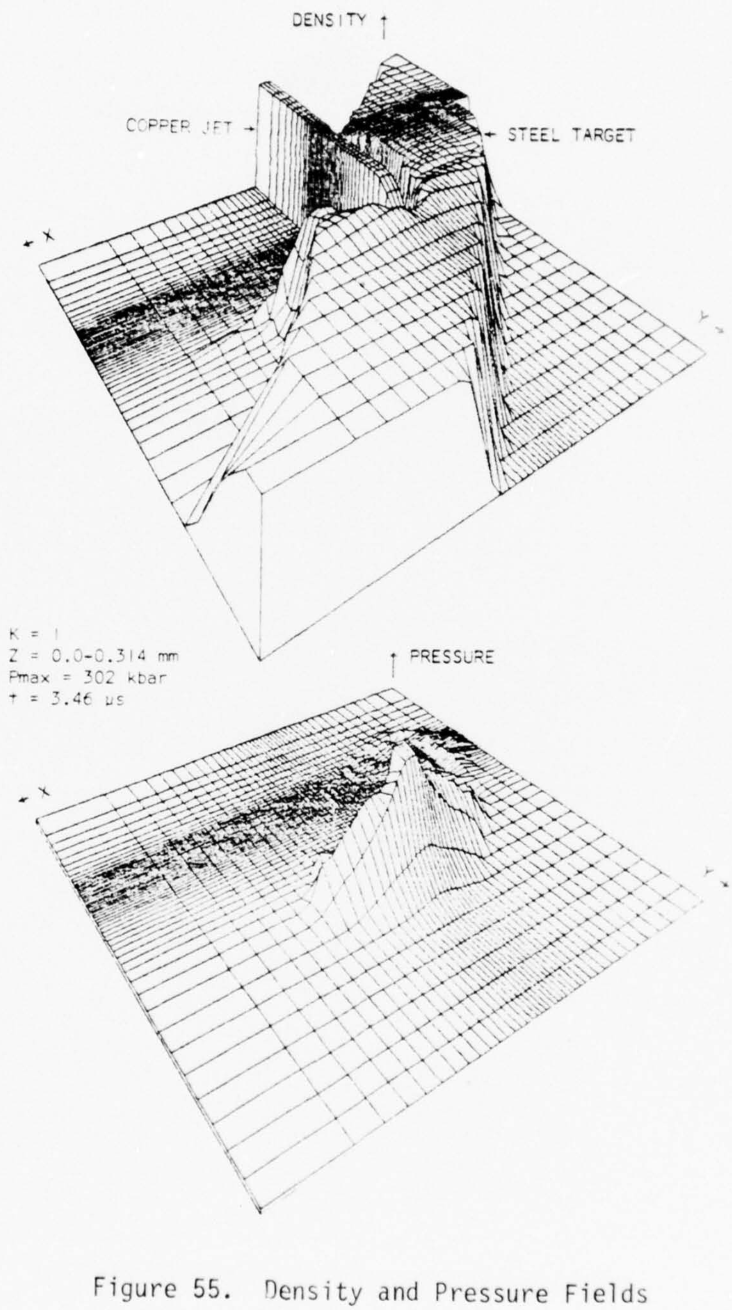

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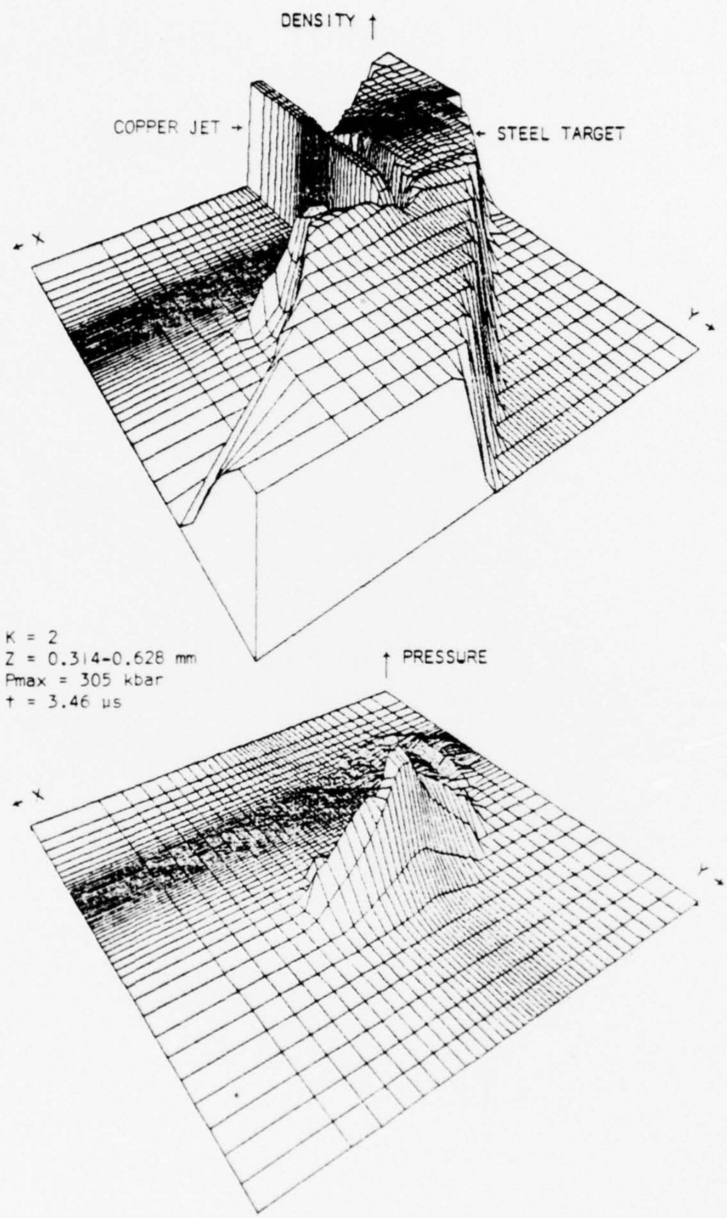

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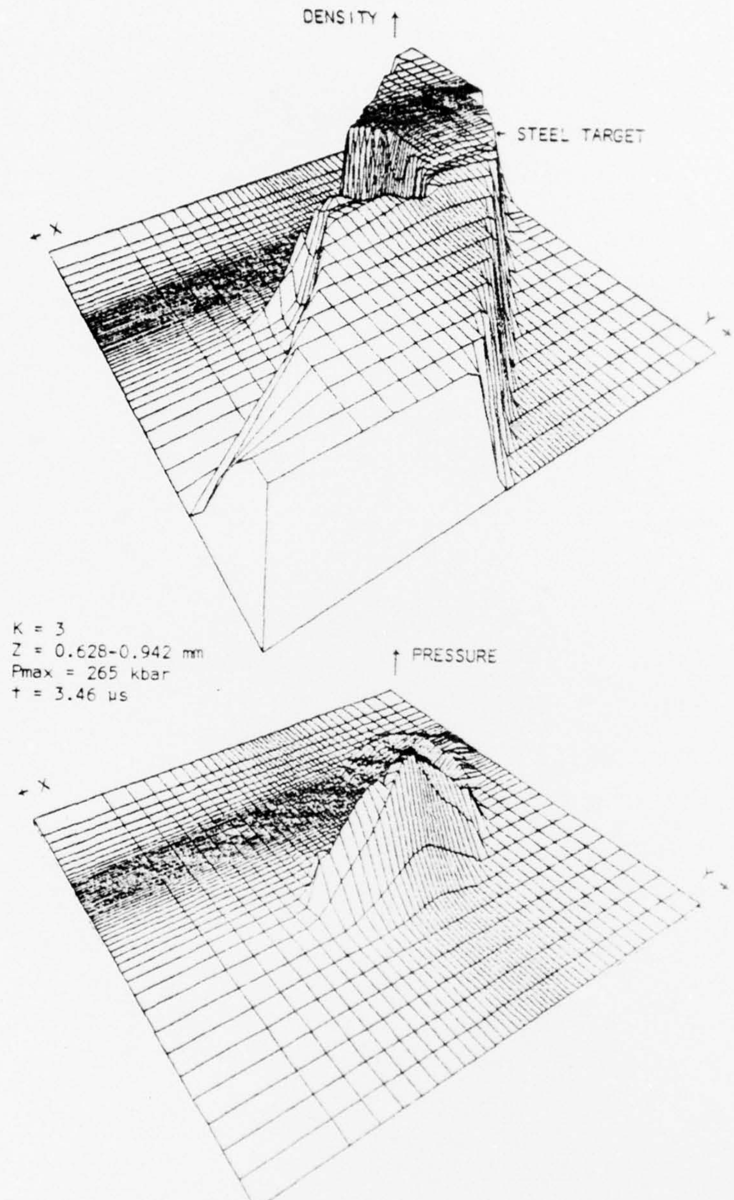

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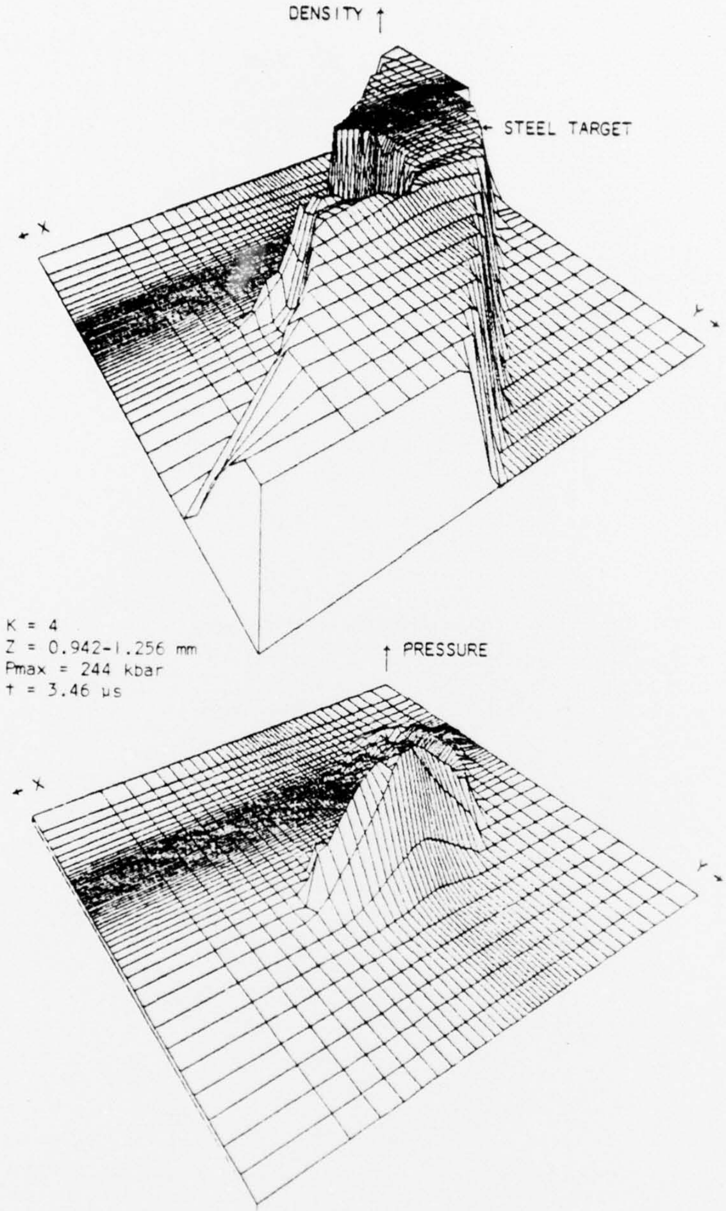

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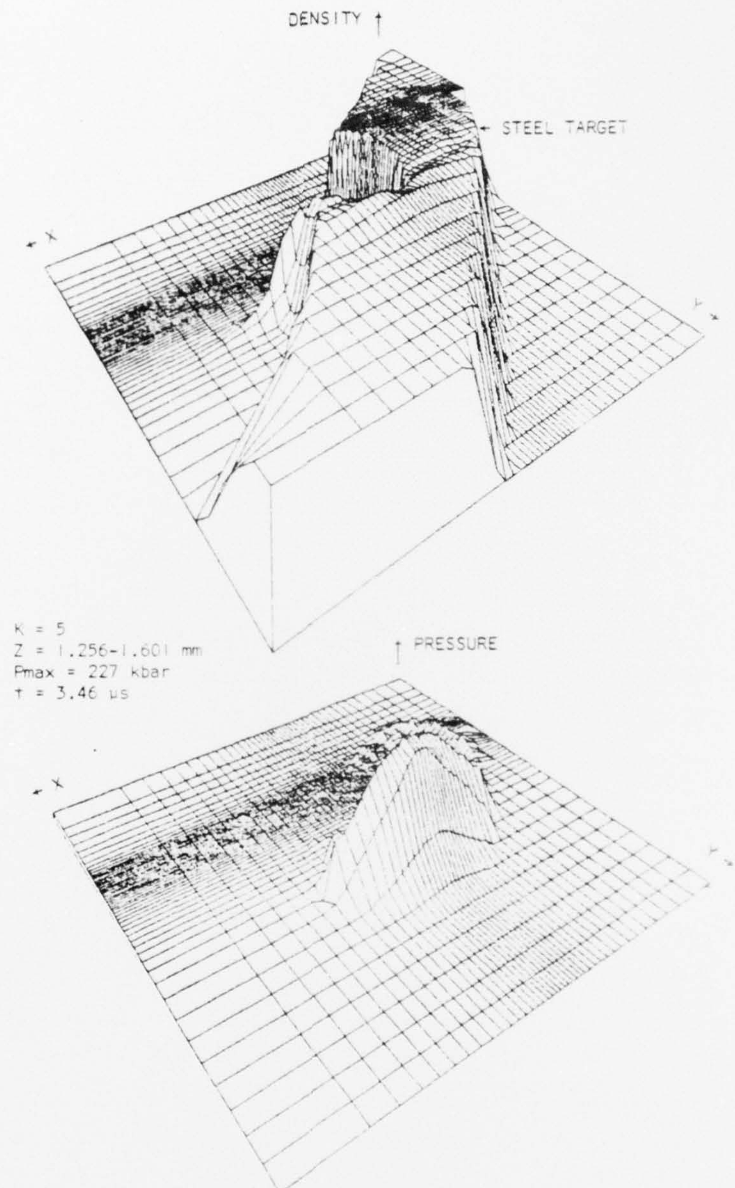

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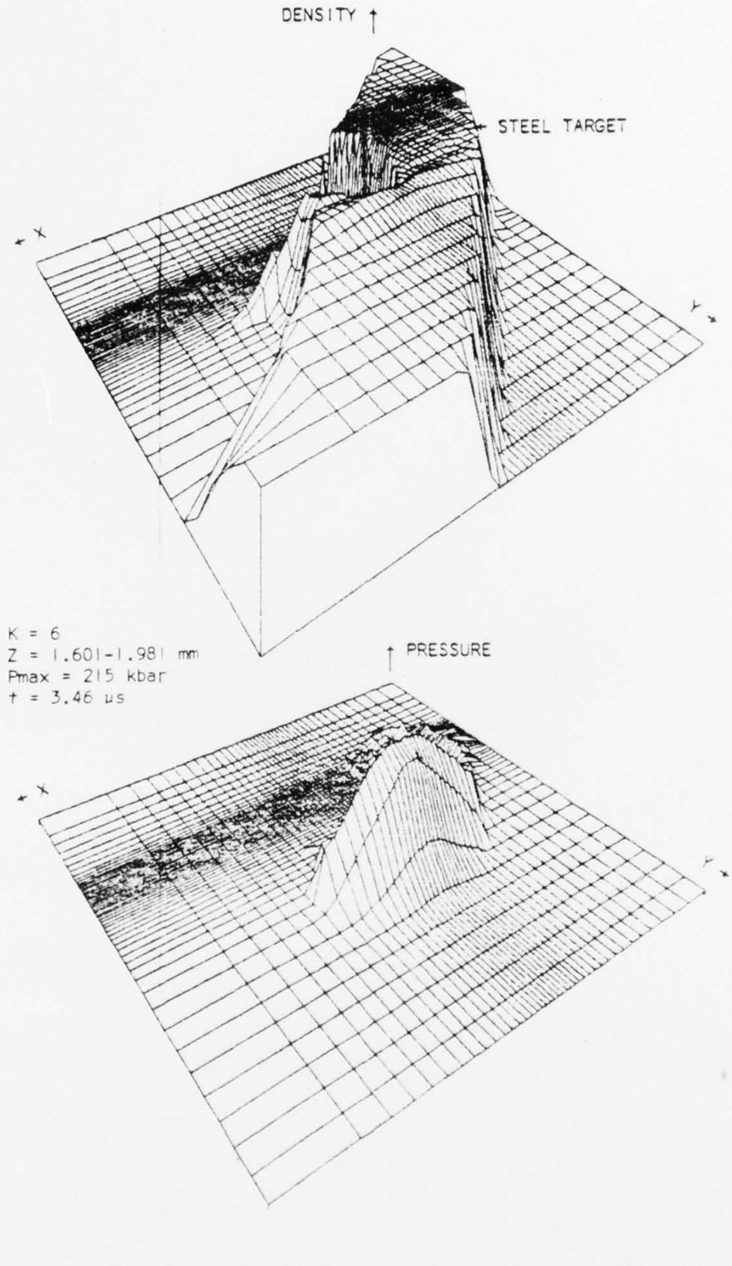

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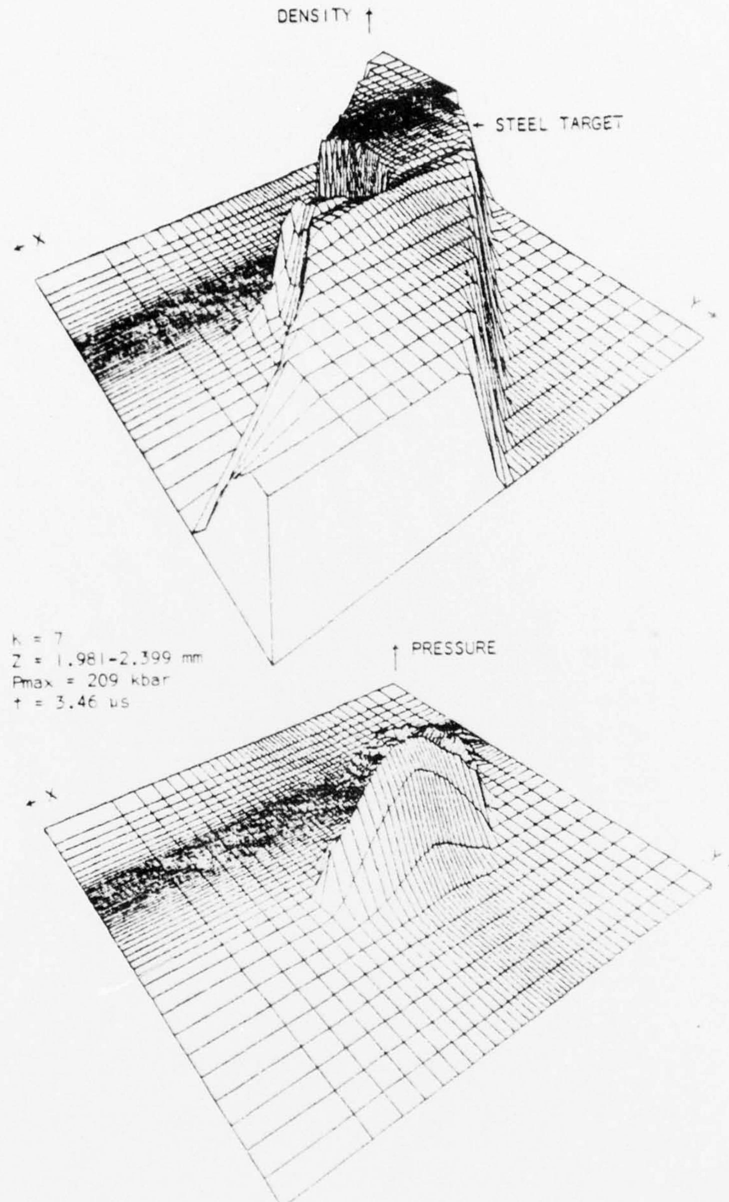

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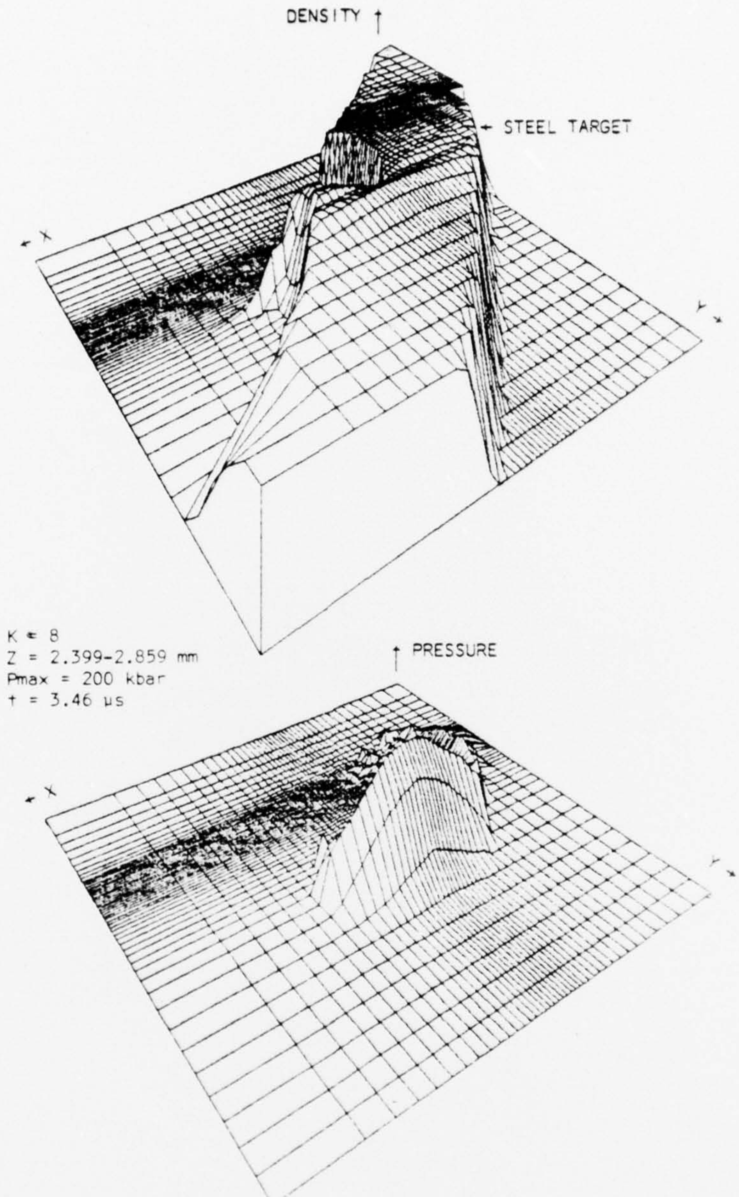

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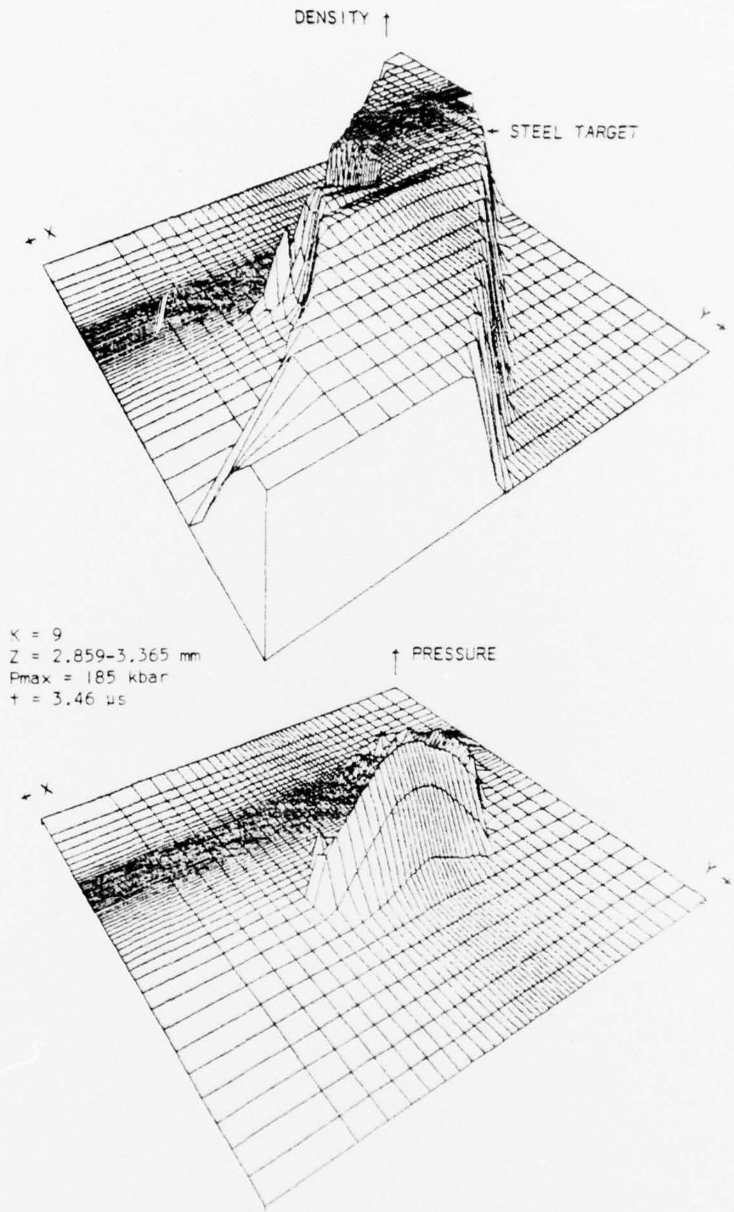

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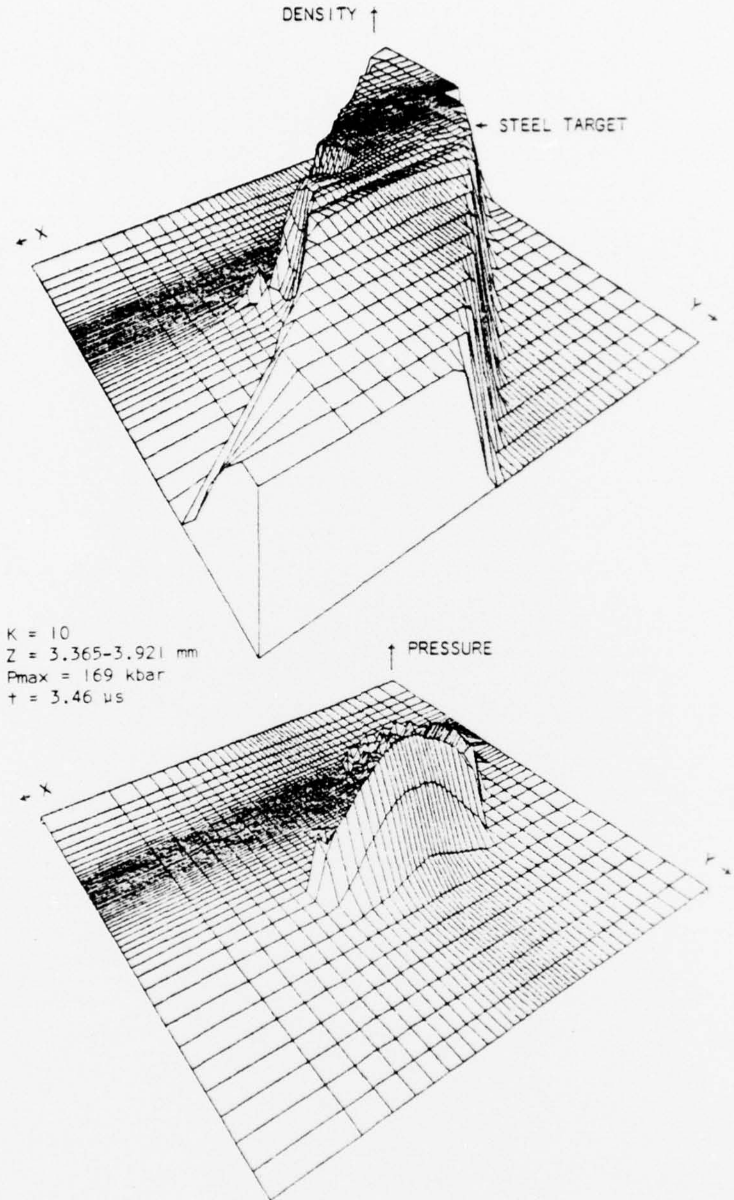

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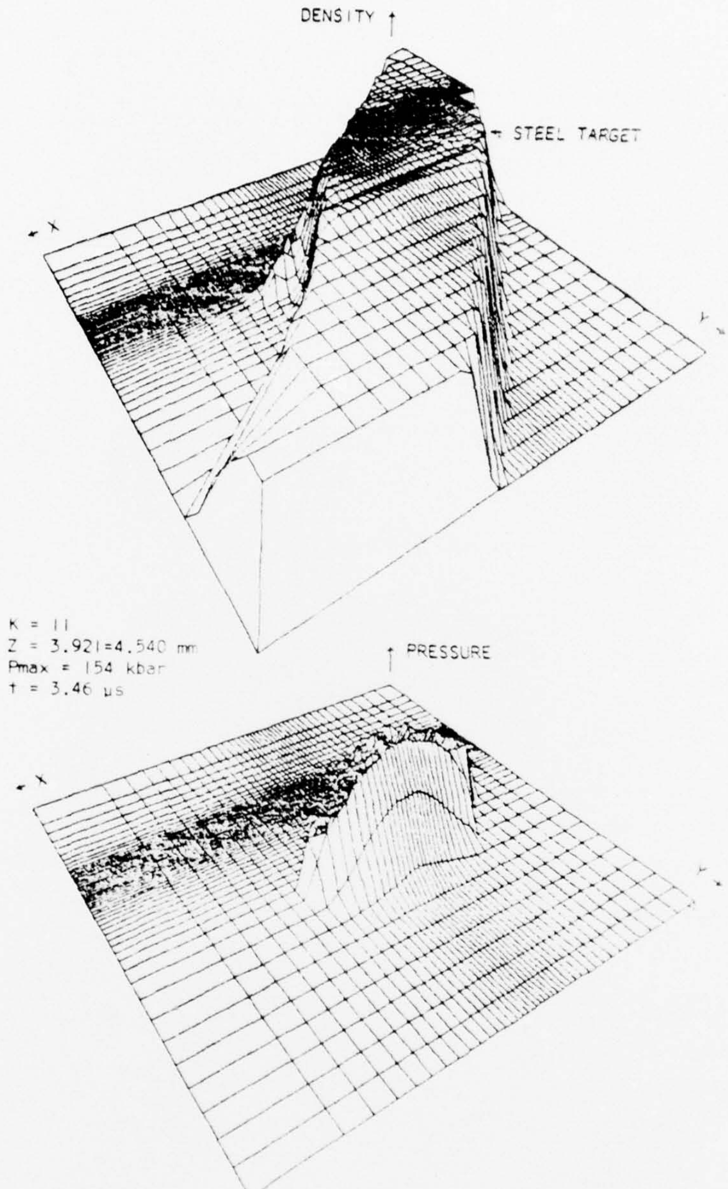

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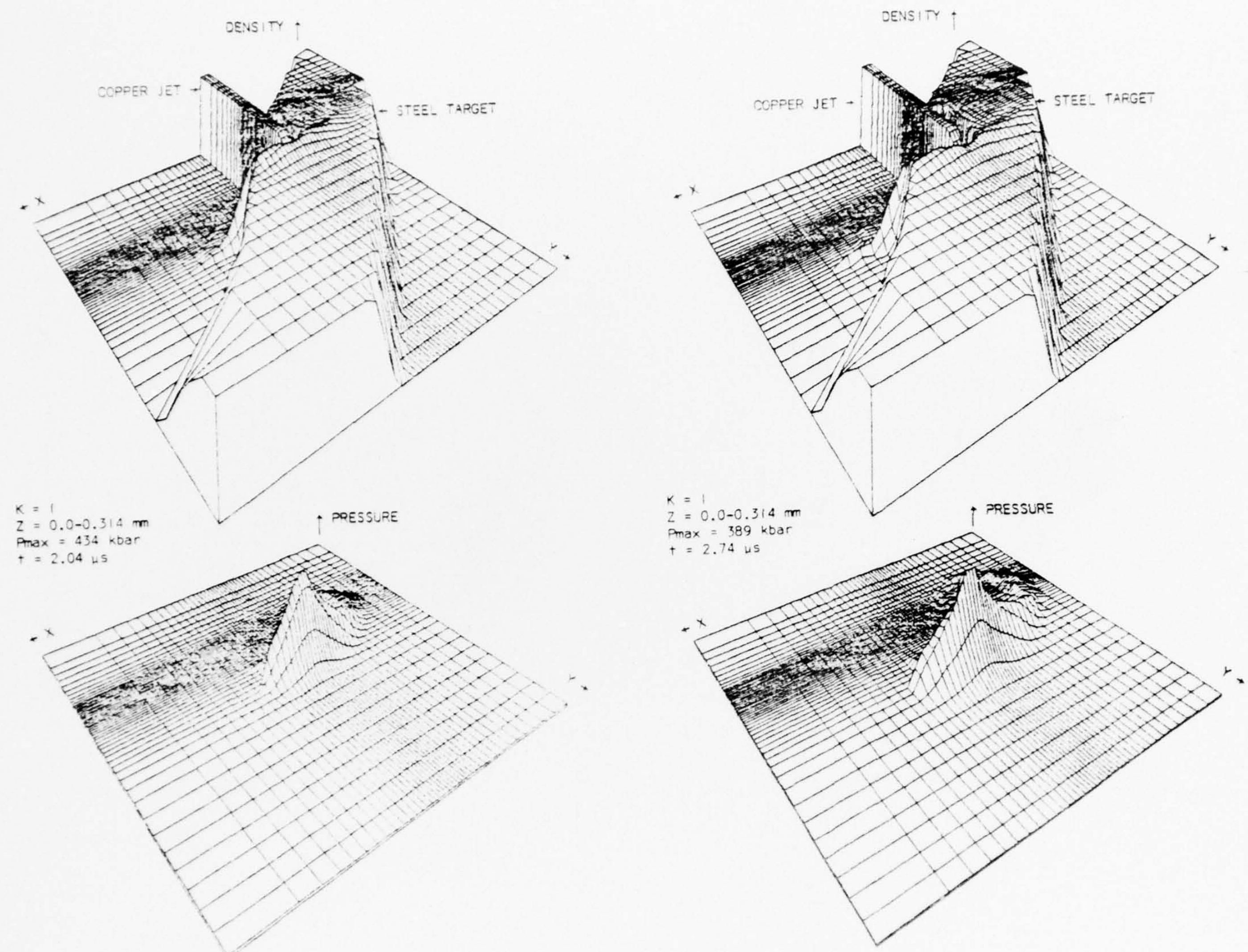

Figure 66. Density Field and Pressure Field Histories

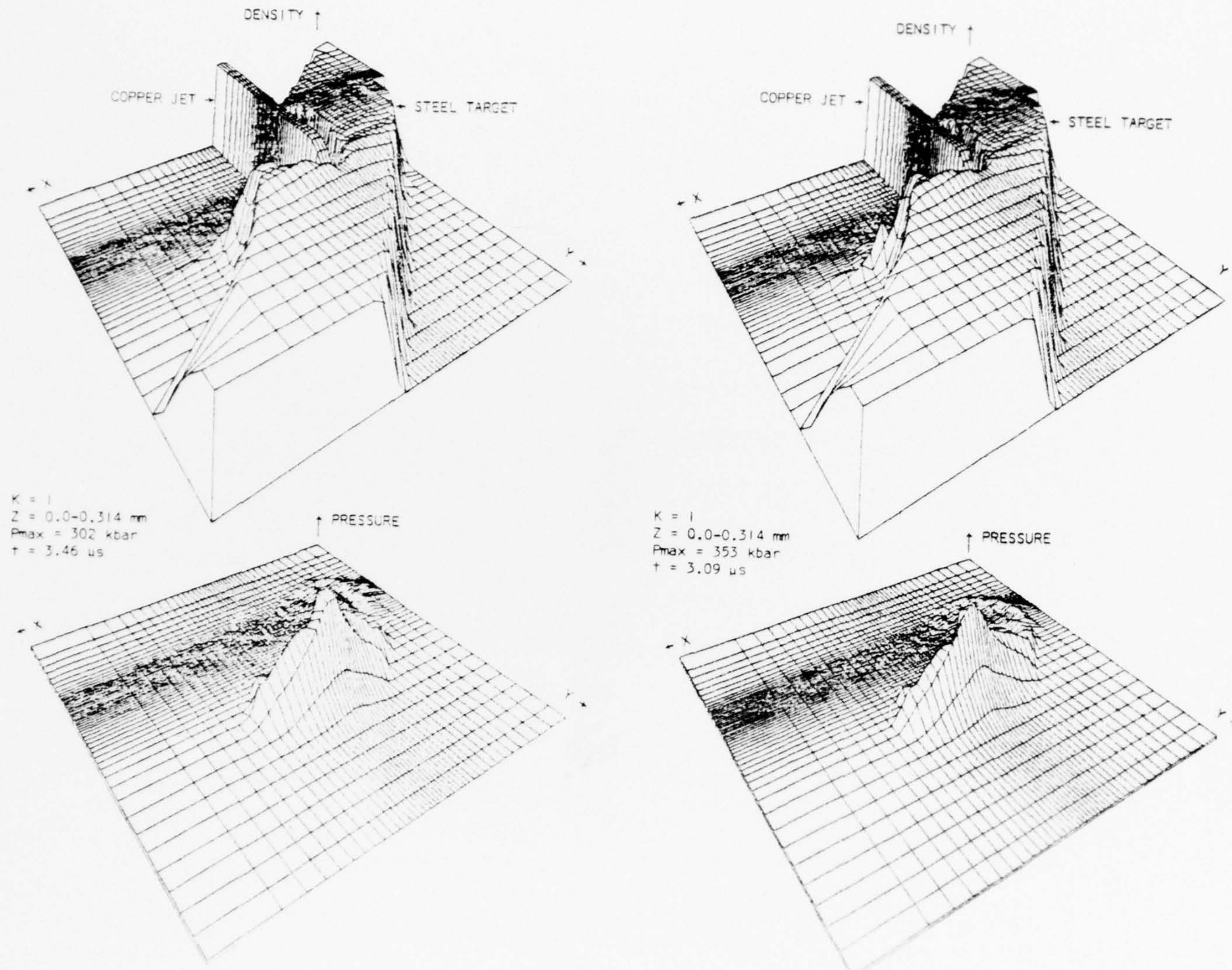

Figure 67. Density Field and Pressure Field Histories

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